DEMONSTRATION REPORT FOR VISUAL SAMPLE PLAN REMEDIAL INVESTIGATION (VSP-RI) SAMPLING METHODS AT THE MOTLOW SITE IN TENNESSEE

**MUNITIONS RESPONSE PROJECT
STATISTICAL VERIFICATION AND REMEDIATION
SAMPLING METHODS (200837)**

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Acronyms

ASR	Archive Search Report
bgs	below ground surface
USACE	U.S. Army Corps Of Engineers
CSM	Conceptual Site Model
DoD	U.S. Department of Defense
EE/CA	engineering evaluation and cost analysis
EM	electromagnetic
ESTCP	Environmental Security Technology Certification Program
GPS	global positioning system
HE	high explosive
MC	munitions constituents
MEC	munitions and explosives of concern
MRS	munitions response site
MSCC	Motlow State Community College
mV	millivolt
PNNL	Pacific Northwest National Laboratory
PRV	post-remediation verification
QA/QC	quality assurance and quality control
RI	Remediation Investigation
SERDP	Strategic Environmental Research and Development Program
TEC	Topographic Engineering Center
TOI	targets of interest
UTM	universal transverse mercator
UXO	unexploded ordnance
VSP	Visual Sample Plan

Acknowledgments

Executive Summary

The U.S. Department of Defense (DoD) is currently removing, or will be removing, munitions and explosives of concern (MEC) from millions of acres of land and sea. The DoD has established and continues to improve the full process of transferring military land for public use. As a part of this continued improvement and to provide greater confidence that the MEC threat is acceptably low, during the Remedial Investigation (RI) stage the DoD requires sites to be adequately characterized to identify and remediate potential target areas where MEC is most likely present and to demonstrate that the risk of MEC (or Targets of Interest [TOI]) on non-target areas is sufficiently low.

With support from the Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP), Pacific Northwest National Laboratory (PNNL) has developed a statistical sampling and analysis software—Visual Sample Plan (VSP)—that helps design transect surveys to detect and delineate target areas, estimate and bound TOI/acre, verify presumptively clean assumptions, and validate the quality of MEC remediation. This report summarizes the objectives and results of a demonstration focused on the Visual Sample Plan-Remediation Investigation (VSP-RI) methodology and modules and how those were used during an actual RI process on the site located in Motlow, Tennessee.

The primary objectives of this demonstration were to evaluate, illustrate, and determine acceptability of the VSP-RI methodology as it is applied to two of three possible application scenarios. The first scenario evaluated was for a region (Area 3a) that had little if any munitions use, and was not expected to contain target areas but needed validation that the TOI rate was confidently low. The second scenario evaluated was for a region (Area 2a) where there was real potential for encountering target areas and it was expected to contain TOI.

In support of the objectives of this demonstration, a transect survey design was developed for Area 3a using the VSP-RI module where the primary objective was to estimate TOI/acre and determine whether one can confidently (i.e., with 90% confidence) conclude that it is less than 0.5/acre. Two options were considered, one in which no prior information was used to design the survey and another in which some prior information was used that was available from remediation of an adjacent parcel. Using the prior information resulted in less survey acreage required and because of limited funding available to perform this survey, that reduced-scope survey option was evaluated. The survey resulted in 43 reacquired anomalies that were subsequently dug with none of those listed as TOI. Based on this finding, a TOI/ac rate of less than 0.5/acre was demonstrated with 90% confidence. This new VSP-RI methodology, which allowed consideration of prior knowledge about the potential number of TOI on the site, required significantly less (about half as much) survey acreage than methods that do not account for prior information or similar methods employed by the UXO Estimator software.

In the other area suspected to contain TOI (known as Area 2a), a more tightly spaced systematic transect survey was designed to support the objective of target-area identification and delineation. Using target-area delineation and kriging methods in VSP, the survey results were analyzed, and several potential target areas were identified based on anomaly densities that were much higher than background density. This confirmed that using VSP transect surveys designed to detect and delineate target areas of concerns does help identify those potential target areas where unexploded ordnance (UXO) presence is most likely.

Area 3a results also were used to demonstrate the use and performance of VSP transect design methods for presumptively clean sites (sites where no TOI is expected but additional geophysical surveys are required for confirmation). This VSP module allows one to state that they are X% confident that at least Y% of all possible parcels of a specified size do not contain TOI if no TOI are found in the limited survey. Because only a limited amount of transect surveying and digging could be performed in Area 3a, it was shown that, with reasonable assumptions on the maximum number of parcels that could possibly contain TOI, one may state with 90% confidence that no more than 5.4% of all possible parcels of ¼-acre size would contain TOI.

It was also demonstrated that the UXO Estimator software tool and the VSP-RI module for estimating TOI/acre and confidently showing that it is less than some value using an uninformative Bayesian prior both require exactly the same amount of survey acreage to be performed. However, this VSP-RI module with reasonable, defensible informed priors can result in significantly reduced required survey acreage while maintaining the desired confidence or significantly increased confidence using the same survey acreage.

Finally, the performance of transect surveys as compared to grid surveys for the TOI/acre estimation and comparison module was examined through a series of simulations, varying the spatial distribution of TOI and other key parameters. We validated previously documented findings that grid sampling is not recommended in most cases because it does not achieve desired confidence levels as well as transect sampling. In fact, traditionally sized transect widths of 1 m and 3 m were quite robust to extreme variations in the TOI clustering patterns. The grid sampling performance was acceptable in a few limited cases and performed poorly as the TOI clustering patterns became more extreme. Results were consistent across designs with varying desired confidence levels (90, 95, 99, and 99.9%). Designs based on confidently estimating rates of 1.5 and 2 TOI/acre were not as robust to TOI clustering.

1   INTRODUCTION

1.1   Background

The U.S. Department of Defense (DoD) is currently performing many remedial investigations (RI) to identify locations where concentrated regions of munitions and explosives of concern (MEC) and unexploded ordnance (UXO) may be present, estimate potential remediation efforts and costs, and support land transfer decisions and no further remediation on some areas. Statistical methods are needed to support transect survey designs and statistical analyses during an RI. These tools need to:

- address the number and spacing of transects needed to detect and delineate target areas
- estimate and map the number and density of anomalies and targets of concern (MEC or UXO)
- demonstrate that the likelihood of targets of concern is sufficiently low to require no further remediation.

Through the Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP), DoD has supported the development of statistical design modules that assist with UXO remediation within Visual Sample Plan (VSP), a statistical support software program developed by Pacific Northwest National Laboratory (PNNL).   Transect survey design and analysis methods have been developed and demonstrated for use on wide-area assessments and post-remediation verification. Several of these VSP methods are also pertinent for some RI objectives. However, some of the previously developed VSP modules have been misapplied at some sites in an attempt to meet specific RI objectives for which VSP was not designed to address. Now, additional methods have recently been added to VSP to support these other important RI objectives.   This demonstration report outlines the steps that were taken to demonstrate the methods in VSP during the actual remedial investigation process on the Motlow, Tennessee, site.

Given these new VSP methods and the need for demonstrating how the new and existing tools should appropriately be used during an RI, this demonstration evaluates these tools on a real site and provides important experience that will be used to develop an RI workflow process within VSP to better guide the user through the VSP-RI experience. This will provide the DoD services and their contractors a single tool for most RI transect design and statistical spatial analyses.

1.2   Objectives of the Demonstration

Under SERDP/ESTCP sponsorship, PNNL developed VSP modules to support wide-area transect design, target-area detection and delineation, anomaly spatial mapping and density estimation, and post-remediation verification. Some of these tools are also applicable within the RI phase of a project. PNNL has recently been developing other modules and enhancements that more fully support other goals of an RI. This demonstration illustrates how all these RI-pertinent VSP tools are used during an RI.

The primary objectives were to demonstrate the statistical and correct implementation of VSP-RI tools to support the RI process on an actual site. Other objectives included supporting the development of an RI transect survey design and statistical analysis process workflow document,

improving VSP online help functionality, and gaining regulator support for this VSP-RI module and process workflow.

1.3   Regulatory Drivers

DoD is required to perform RIs on many sites where explosive risks are of concern. Regulatory and DoD objectives require that a defensible evaluation be performed during an RI to identify any areas where remediation likelihood is high and/or validate no further remediation as well as establish use controls. In these areas, sufficient information is needed regarding the number and spatial distribution of anomalies, the expected number of UXO and/or MEC, and the boundaries of the areas that must be remediated. Based on this and other relevant information, various remediation options can be explored during the follow-on feasibility study.

Regulators have expressed concerns that VSP methods developed for wide-area assessment or post-remediation verification purposes have been misapplied during RIs. DoD also developed RI requirements that contractors have interpreted to suggest that VSP can be used to meet those RI requirements. Based on the misapplication concern and the need for a complete VSP-RI toolkit that addresses a more complete suite of RI objectives, new VSP-RI methods have been developed and demonstrated on this Motlow site application.

The ESTCP office also established a VSP-RI advisory group consisting of regulators, DoD staff, and contractors to guide the development of this VSP-RI module. This group has been instrumental in identifying all pertinent RI objectives and decision rules that have led to the development of the VSP-RI module. They have also been briefed on this methodology as it has been applied within this demonstration.

2   TECHNOLOGY

2.1   TECHNOLOGY DESCRIPTION

With sponsorship from US Departments of Energy, Defense, and Homeland Security and the U.S. Environmental Protection Agency, PNNL has developed VSP. VSP is a software tool that supports the development of a defensible sampling plan based on statistical sampling theory and the statistical analysis of sample results to support confident decision-making. VSP couples site, building, and sample location visualization capabilities with optimal sampling design and statistical analysis strategies. VSP is currently focused on design and analysis for the following applications:

- environmental characterization and remediation
- environmental monitoring and stewardship
- response and recovery of chemical/biological/radiation terrorist event
- footprint reduction and remediation of UXO sites
- sampling of soils, buildings, groundwater, sediment, surface water, subsurface layers.

Under the SERDP and ESTCP programs, several VSP modules have been developed and demonstrated to support sites where unexploded ordnance is a primary concern. Initially, methods were added to VSP to support the wide area assessment objectives of transect design,

target-area detection and delineation, and anomaly density mapping and estimation. Later, methods were included to support post-remediation verification efforts.

Now an additional set of VSP tools have been developed that are focused primarily on RI objectives and are the subject of this demonstration on a real site. During an RI, typically there are three types of areas encountered within a munitions response site (MRS).

- **Type-1 Areas**: Areas with known munitions use and or suspected target areas.
- **Type-2 Areas**: Areas with no clear target area discovery needs (regions around known target areas that have some potential munition use or areas with known munitions use but no clear target at which munitions were fired).
- **Type-3 Areas**: Areas that are presumptively clean but more evidence is required to support this claim.

The decision objectives and therefore survey and analysis objectives are different for each of these types of areas. Below, the primary decision/survey objectives and most appropriate VSP tool is presented for each type of area.

2.1.1 Type-1 Areas

These are areas where targets areas are known or are likely to exist, but the amount and location are uncertain. The primary VSP-RI survey purposes then are to:

- identify any target areas if they exist
- delineate identified target areas
- estimate the number of anomalies or anomaly density
- explore the spatial anomaly distribution.

Other objectives include distinguishing between culturally cluttered high anomaly density areas and munitions related areas and exploring the nature and types of munitions.

For Type-1 areas, the VSP tools developed for wide area applications are directly applicable and were used in this demonstration and many previous demonstrations. These tools help the user determine the required transect spacing needed to have a high probability of detecting target areas of concern. The technical descriptions and underlying mathematics/statistics have been adequately covered in previous wide area assessment demonstration plans and reports. An example is shown in Figure 1.

No new design tools were implemented in VSP to address the Type-1 areas as they already exist. This demonstration included improved statistical uncertainty methods for bounding target areas and the density estimate within the target area.
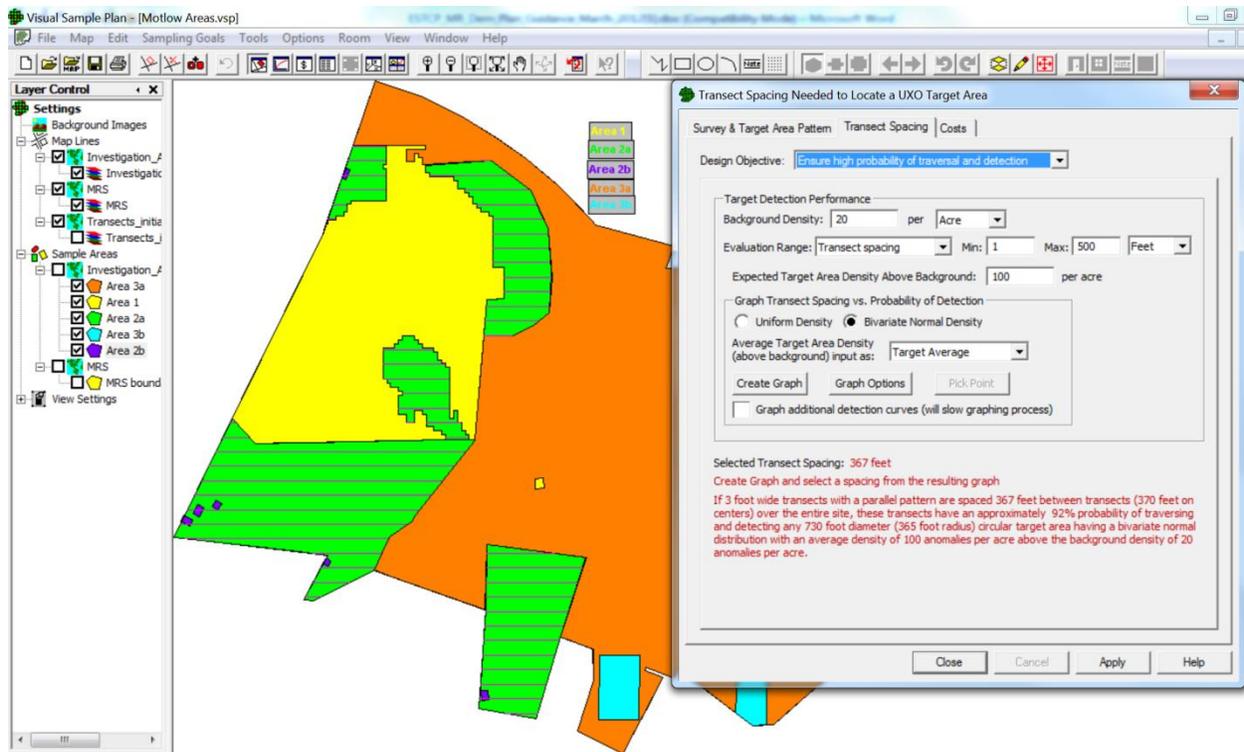
Figure 1. VSP Screen Shot of Target-Area Detection Survey Design

2.1.2   Type-2 Areas

These are areas where target areas are very unlikely but some limited munitions use is possible. For these areas, the primary objective is to estimate targets of interest (TOI)/acre (or MEC/acre or other rate) or the number of possible TOI (or MEC or other count) and show confidence that it is less than some pre-specified limit.

For Type-2 areas, a new VSP module has been developed. This module helps determine the survey acreage required and the number of randomly placed transects needed to confidently demonstrate that the rate of the TOI (e.g., UXO/acre) is less than a specified limit. This method also ensures that at least one TOI will be discovered with X% confidence, if the TOI rate actually is above the specified limit. Figure 2 shows the VSP user input dialog box for this tool.
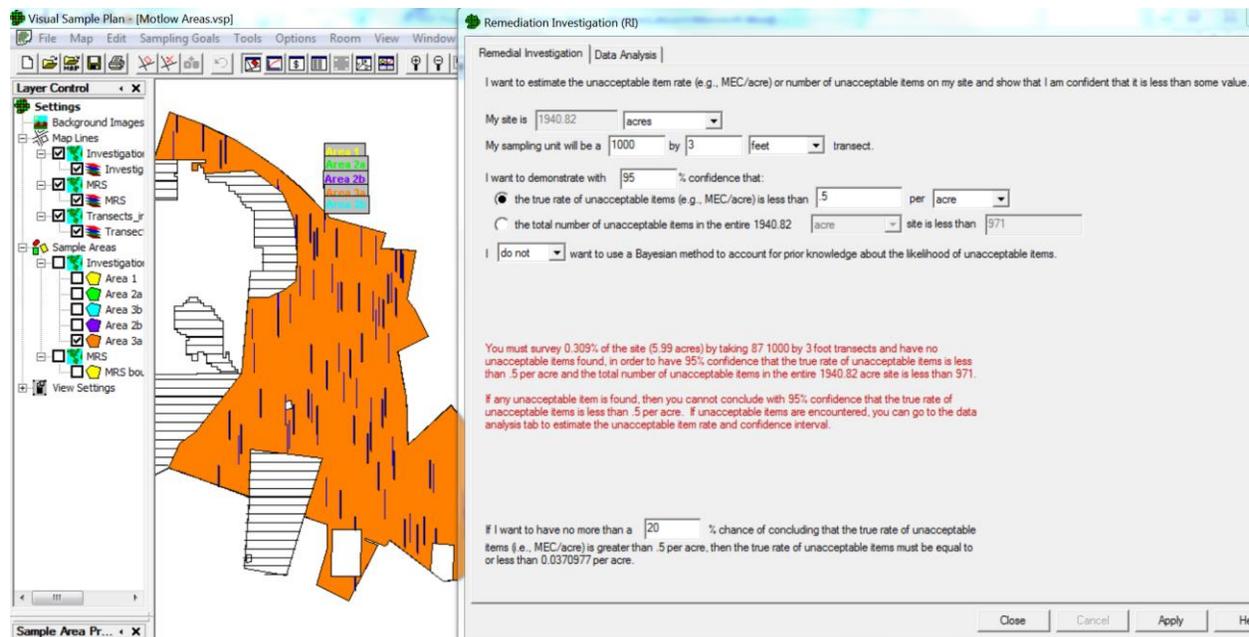
Figure 2. VSP Screen Shot of Non-Bayesian UXO/Acre Estimation and Bounding Survey Design

Both a non-Bayesian and Bayesian approach are available within this new VSP tool. The Bayesian approach requires additional input and assumptions as shown in Figure 3. It should be noted that, if the user chooses a non-informative prior, the amount of survey acreage required will be the same as the amount that the UXO-Estimator tool outputs. This VSP tool can provide substantially less required survey acreage than the UXO-Estimator if an informative prior is used. In many cases, an informative prior in the form of "I'm quite sure that the maximum number of UXO on my site is less than Y." is easily justified and can result in less required survey acreage. This demonstration illustrates how this tool is used for a Type-2 area.
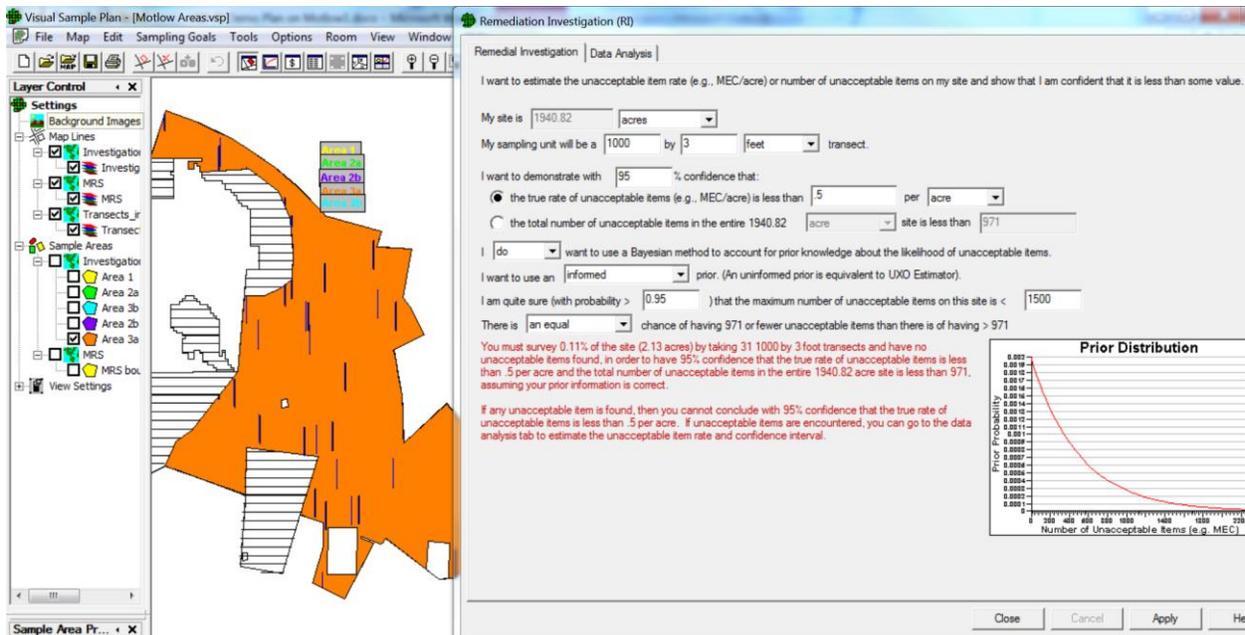
Figure 3. VSP Screen Shot of Bayesian UXO/Acre Estimation and Bounding Survey Design

2.1.3 Type-3 Areas

These areas are presumably munitions-free based on a lack of evidence that any munitions were used within them. Although some may argue that these areas should not be included in an RI, many sites are encountering such areas and they are required to either support their presumed clean-site assumption with additional documentation and historical evidence or perform a few transect surveys to provide additional confirmation. This approach requires that the users carefully define what would constitute a TOI. TOI could be defined in a number of different ways including:

- items of explosive hazard
- any fragments related to high explosive munitions
- any munitions debris.

For these areas, two objectives may be possible that would drive the transect survey design requirements.

- Show that you are X% confident that at least Y% of all possible parcels of a prescribed size do not contain TOI.
- Estimate TOI/acre (such as MEC/acre or some other rate) or the number of possible TOI (e.g., MEC or UXO) and show that we are confident that it is less than some pre-specified limit.

The second objective is the same as that for the Type-2 areas and would draw upon the same VSP tools outlined in that section. For the first objective, a new VSP user dialog has been developed. This new VSP tool draws upon the same underlying mathematical model as the VSP post-remediation verification (VSP-PRV) module, but the user input dialog structure was

changed to better reflect RI objectives and avoid misuse of this tool. The VSP-PRV user dialog is shown below in Figure 4.
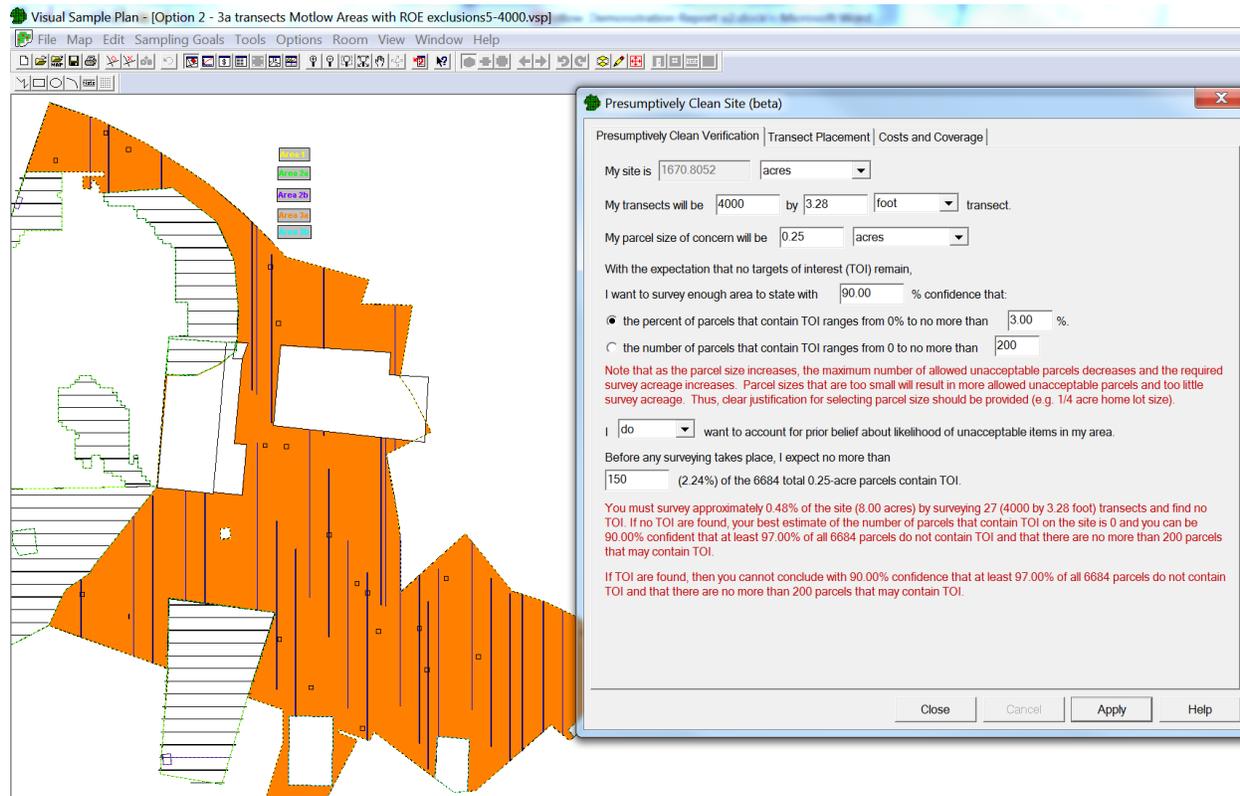
Figure 4. VSP Screen Shot of Presumptively Clean Survey Design

This new VSP module for presumptively clean sites requires the user to specify a parcel size of interest and solves for the survey acreage required to make statistical statements about parcel equivalent areas. Non-Bayesian and Bayesian options exist to provide the user flexibility if prior information is available. For example, if on similar sites or historical use of similar sites suggests that the likelihood of TOI within parcels is rare, that information can be accounted for to reduce the survey acreage required and increase the confidence of few if any TOI in the parcels.

2.2   ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The VSP-RI modules provide all the transect design and statistical analysis tools needed to support RIs. Having a single software tool with clear instructions on which module is appropriate for a particular RI objective and type of area significantly improves the standardization and technical defensibility of RI studies on DoD sites.

UXO Estimator is a software tool that has been used to determine the required acreage for one of the RI objectives. However, this tool has several limitations. It only provides the amount of survey acreage required when the objective is to estimate (or confidently bound) MEC or UXO per acre and has no ability to apply a random selection of transects on maps. It also assumes an uninformed Bayesian prior, which suggests that the likelihood of many, many UXO is the same

as the likelihood of few UXO. The VSP-RI module overcomes these limitations and also addresses the other RI objectives.

3   PERFORMANCE OBJECTIVES

The primary objective of this demonstration is to demonstrate the validity and applicability of the VSP-RI modules through onsite demonstrations and with simulations. Specific objectives include:

1. Clearly identify the application of the VSP-RI module and methodologies for three types of areas within an MRS and show how the decision objectives and VSP module use are different for each type of area.
2. Gain real site application experience that can be used to guide the development of an online workflow process for VSP-RI use.
3. Evaluate usability of VSP user dialogs and identify needed improvements.
4. Provide comparison of VSP-RI methodology to UXO Estimator results.
5. Evaluate performance of transects versus grids when applying UXO/acre estimation objective and provide recommendations of appropriate transect dimensions (this will require simulations).
6. Compare the utility of target area boundary delineation methods and density estimation uncertainty.

Each of these performance objectives is defined and summarized in Table 1. Some performance objectives were accomplished using the Motlow, Tennessee, site demonstration and others required a simulation study.

Table 1. Performance Objectives

Performance Objective	Metric	Data Required	Success Criteria
Motlow Site VSP-RI Demonstration Performance Objectives			
1. Show application of VSP-RI modules for 3 types of areas	Application of the VSP-RI modules to three different types of areas within Motlow site.	• Clear agreement on decision objectives for the 3 types of areas. • Transect surveys • All identified anomalies to be dug	• Well delineated target areas (see description) • Estimate an upper bound on TOI/acre • Acceptance of transect design input parameters.
2. Experience for developing VSP-RI workflow process guidance.	Agreement within VSP-RI advisory committee of general workflow process.	• Summary of all steps in workflow consistent with site work plan • Information on objectives and decision criteria for each area within MRS	Draft of VSP-RI workflow process developed.

Performance Objective	Metric	Data Required	Success Criteria
3. Demonstrate usability of VSP-RI modules and identify needed improvements.	Contractor understanding/use of VSP-RI and list of recommended improvements.	• Transect surveys • Dug anomalies • Contractor feedback	Successful application of VSP-RI modules and minimal list of needed improvements.
4. VSP-RI module comparison with UXO Estimator	Cost of transects and simplicity of use. Demonstrate that VSP and UXO Estimator answers are same when same assumption is used.	• Cost of transect surveys • Survey acreage required under each	VSP-RI survey acreage required is same as UXO estimator under certain conditions. VSP-RI shown to require less acreage under alternative assumptions.
5. Evaluate performance of transects vs. grids for UXO/acre estimation objective and spatial coverage index.	Desired confidence equals achieved confidences for simulations where UXO spatial density patterns and number of UXO are varied	• Simulated site data varying spatial distribution and number of UXO.	Guidance to provide VSP-RI user help on selecting transect surveys or grid surveys.
6. Compare the utility of different possible target area boundary delineation methods.	• Ease of use • Are boundaries, based on systematic transects, sufficiently bounding high-density areas for future remediation efforts?	• Synthesized scenarios and transect surveys • Actual Transect surveys • Delineation objectives (e.g., confidence boundary area is associated with target area or not associated with background)	• Boundary tools support cost estimation and associated uncertainty of remediation needs. • Boundary delineation results on synthesized sites are conservative (meet or exceed specified delineation objectives).

3.1 Objective 1: Show Application of VSP-RI Modules For Three Types Of Areas

There was a need to clearly illustrate the application of the VSP-RI module and methodologies for the three types of areas typically found within an MRS during an RI as outlined in Section 2. The decision objectives and survey design requirements and, hence, the VSP module selected depend on the type of area being dealt with. The Motlow site had areas within the MRS that represent these three types of areas. A primary objective was to demonstrate which VSP-RI module is most appropriate for each type of site and illustrate its use. In summary, the three areas and recommend VSP modules are:

- Known munitions use at specific but unknown target locations (target area discovery with systematic transect design).
- Potential munition use with no clear firing at targets (RI rate estimation with systematic or random transect design).
- Little to no known munitions use site (presumptively clean) with stake holder or regulatory driver for validation of assumptions (RI rate estimation or verification sampling with random or systematic transect design).

3.1.1 Metric, Data Requirements, and Success Criteria

Demonstrating a successful application of the VSP-RI modules to the Motlow site was the primary metric for this task. The geophysical survey data from transects that were designed using VSP along with anomaly locations, dig results, and types of munitions found were required. Success is defined as good estimates of and upper bounds on TOI/acre, and acceptance of transect design input parameters by project team and regulators. Although we wanted to demonstrate the performance of improved quantifiable target-area delineation methods (see performance objective 6), these new delineation methods were not sufficiently mature to use on this demonstration.

3.2 Objective 2: Gain Experience for Developing VSP-RI Workflow Process Guidance

There are several VSP tools that are appropriate for different aspects of the RI process and under certain conditions. To avoid misuse of VSP, ESTCP requested that we develop online guidance on using VSP for RIs at each step of the workflow process. This demonstration provided valuable experience in working through an RI on a real site. This experience was used to guide our development of the VSP-RI workflow process guidance. It also gave us a specific site context to use in our discussions with the VSP-RI advisory committee as we developed this workflow guidance system.

3.2.1 Metric

Acceptance by our VSP-RI advisory committee of a draft VSP-RI workflow that has now been developed based on the experience gained from this demonstration.

3.2.2 Data Requirements

The geophysical survey data from transects that are designed using VSP along with anomaly locations, dig results, and types of munitions found were required.

3.2.3 Success Criteria

Success was measured through the development of a draft outline of the RI workflow process as it pertains to all VSP-RI modules and identifying which modules should be used at each step of the RI process to satisfy each RI objective.

3.3 Objective 3: Evaluate Usability of VSP and Identify Needed Improvements

As we used the VSP-RI modules within this demonstration, we identified needed changes to the user dialogs, processing algorithms, outputs, or other features. This objective captures the need for continuous improvement within VSP to improve ease of use, protect against misuse, and provide needed information for decision-making.

3.3.1 Metric and Data Requirements

An important metric was whether the contractor understood how to properly apply the VSP-RI modules. A list of recommended improvements was also an important metric. Data requirements are the same as 3.2.2 above.

3.3.2 Success Criteria

Contractor feedback on ease of use and VSP clarity determined success. Also, the recommended VSP improvements were minimal, such that the quality of the initial VSP-RI modules was deemed acceptable.

3.4 Objective 4: VSP-RI Module Comparison with UXO Estimator

There are multiple VSP-RI modules that are applicable under different RI objectives. One of those modules focuses on providing an estimate of TOI/acre and showing that it is less than some pre-specified limit. One of the options under that module involves a Bayesian statistical model. When an uninformed Bayesian prior is selected as input into this VSP module, the amount of survey acreage calculated is the same as that calculated by UXO Estimator given the same input parameters. This performance objective is to illustrate VSP-RI vs. UXO Estimator equivalence using various input parameters and to contrast the VSP-RI methodology against UXO Estimator results when other assumptions are used.

3.4.1 Metric

Reduced survey acreage for comparable performance objectives resulting in cost savings was a key metric. Demonstrating simplicity of use and equivalency of VSP-RI module with UXO Estimator using certain inputs were also important metrics.

3.4.2 Data Requirements

We used dig information on the identified munitions items from previously remediated areas (See Figures 5 and 6), currently called Area 1 to form the basis for the Bayesian priors used in the VSP-RI module. Other data requirements are shown in Section 3.2.2.

3.4.3 Success Criteria

An equivalence of the VSP-RI and UXO Estimator results for the uninformed prior case provides a successful demonstration. Also showing that the VSP-RI module results in less survey acreage required than the UXO Estimator, thereby resulting in significant cost savings, when reasonable assumptions are used demonstrates success.

3.5 Objective 5: Evaluate Performance of Transects Vs. Grids for UXO/Acre Estimation Objective and Spatial Coverage Index

Most RI projects want to complete their survey objectives with sampling units that are as large as possible as it makes application easier. Many RI projects have used grids to meet the required

area objectives as grids provide an easier area for reliably picking targets from the surveys as compared to transects. Other previously supported sampling design software products have promulgated the use of grids. In this objective, we explore the performance of grid-sized decision units (100 x 100, 50 x 50, and 50 x 100 meter) and transect-sized decision units to be a representative sample when estimating the TOI rate within a study area. Within this demonstration, we explore the tradeoffs between transect and grid sampling through simulations and determine whether guidance and spatial coverage metrics should be added to VSP-RI modules in the future.

3.5.1 Metric

In the simulation study, the metric that supports the use of varied sampling unit dimensions is whether the simulated confidence matches the designed confidence within the simulation error tolerance. We evaluate this performance from repeated samplings using different transect dimensions and varied TOI spatial density patterns and TOI rates.

3.5.2 Data Requirements

Simulated sites that vary the number of TOI, their spatial distribution, and TOI/acre are required.

3.5.3 Success Criteria

The recommended sampling units meet the designed confidence for the majority of applications of the RI design tool.

3.6 Objective 6: Compare the Utility of Different Possible Target Area Boundary Delineation Methods

One objective of an RI is to delineate target areas for future remediation. An inaccurate delineation can result in either an over or under estimation of the remediation costs. VSP currently has reproducible boundary delineation tools that can automatically delineate target areas when the user specifies a threshold between background and high-density areas. However, the appropriateness of this threshold is not currently quantified in VSP nor are the uncertainties in the specified boundary. We are exploring different possible VSP additions to help users quantify the results of the boundary of delineated target areas and explore the sensitivity of remediation costs to changes in the boundary. We planned to use synthesized target areas to measure the performance of the developed delineation quantification methods. We also planned to demonstrate the tools on previously bounded high-density areas and some of the high-density areas identified at the Motlow site. However, we were unable to achieve this objective in this demonstration because of the complexity of the new delineation methodology that has delayed its development in VSP. When these methods become available, we plan to use data from the Motlow demonstration to test and demonstrate them .

The objective of the quantifiable boundary of delineation is to provide a statistical statement of confidence in the boundary's effectiveness of containing area associated with the high-density area and not containing area associated with the observed background rate and distribution.

3.6.1   Metric

We planned to use the synthesized data as a baseline and the boundary delineations based on varied applied transect spacings to validate the quantifiable delineation methods.   With synthesized high-density areas, the metric would be reported as percent of the high density correctly bounded. With respect to the Motlow site data, in the future we will determine ease of use and functional utility of each boundary delineation methodology based on our own use and feedback from users.

3.6.2   Data Requirements

The geophysical survey data from transects that are designed using VSP along with anomaly locations, dig results, and types of munitions found are required.   We also will generate synthesized sites and target areas for evaluation and demonstration of the methods quantified statistical performance.

3.6.3   Success Criteria

Again, because of the delay in delineation methods development, this performance objective cannot be achieved during this demonstration.   However, in the future, we will use data generated during this demonstration for testing and evaluation, and success will be measured by whether an improved more accurate quantifiable target area delineation tool can be provided or whether just providing a cost/boundary sensitivity analysis function is sufficient to meet the DoD cost estimation objectives.   A successful method is one that correctly bounds the high-density area within the prescribe data quality objective.

4   SITE DESCRIPTION

4.1   Site Selection

The Motlow Range near Tullahoma, Tennessee, was selected for this demonstration because several site-selection considerations were met. First, the site is scheduled for an RI within the time frame required for our demonstration. The draft work plan was already under development but the site managers, U.S. Army Corps of Engineers (USACE), and regulators were open to some modifications in the work plan that were required to meet our demonstration objectives.

The site also contained two and perhaps three of the types of areas we needed for this demonstration. The contractor had already been using VSP to support transect survey design requirements and was very interested in learning more about the new VSP-RI methods and applying them on the Motlow site.

4.2   Site History

In 1941, the Motlow Range was created by leasing approximately 4000 acres of land approximately 3 miles west of Tullahoma, Tennessee. The Motlow Range was developed as an auxiliary training area for Camp Forrest, one of the U.S. Army's largest training bases during World War II. Camp Forrest, located approximately 5 miles east of Tullahoma, did not contain an adequate amount of land for artillery firing; therefore, the U.S. Government partially solved

this issue in 1940 by leasing 36,000 acres for the creation of Spencer Artillery Range. The Spencer Range, however, was about 50 miles from Camp Forrest, so Motlow Range was created to develop nearby firing ranges for light artillery, mortars, and machine guns. Additional leases were subsequently established to augment the original land, building Motlow Range to approximately 7528 acres. Firing ranges within Motlow were typically oriented toward an interior impact area, which supported activities such as an anti-tank range, anti-aircraft (towed target) range, aircraft machine gun range, and various small arms ranges. By 1943, maneuvers taking place at the Motlow Range involved more than 13,000 troops. Based on the archives search report supplement (USACE 2004), nine ranges were located at the Motlow Range. These overlapping ranges total 3646 acres.

By 1946, Motlow and its ranges were deactivated by the U.S. War Department and declared surplus. The USACE South Atlantic Division conducted a preliminary inspection to determine the requirements for additional de-dudding operations in December 1954. This inspection revealed evidence of 60-mm and 81-mm mortar shells, as well as 30- and 50-caliber shells, hand grenades, and rifle grenades. It was recommended that the impact areas be burned to remove undergrowth and dead vegetation to allow ordnance searches and issuance of a certificate of clearance. Clearance activities were performed over 3604 acres from 1955 to 1956, with subsequent periodic inspections from 1957 through 1969. Occasional recoveries of a variety of ordnance were reported during these inspections.

Several MEC-related studies were completed previously at the Motlow Range. Summaries of the results of the prior investigations and removal actions are provided below and in Figure 5. As noted below, the majority of the MEC finds were along the western portion of the MRS.

1994 Archives Search Report. The USACE Rock Island District conducted a site visit and historical data collection for the former Motlow Range in 1994. The findings were documented in the archives search report (ASR) (USACE 1994). The ASR provided a detailed history of the site (including historical ordnance at the site), summarized the results of the visual site inspection, and evaluated potential hazards associated with ordnance. The former range was divided into 11 areas for the ASR site visit: Area A through Area K (Figure 5). All areas, except Areas F and G, were characterized as confirmed or potential areas containing a threat due to the suspected presence of ordnance. Area F was used for small arms training only, and Area G was not associated with any munitions-related activities. These area designations were adopted by and referenced in several subsequent removal actions and studies (see below).
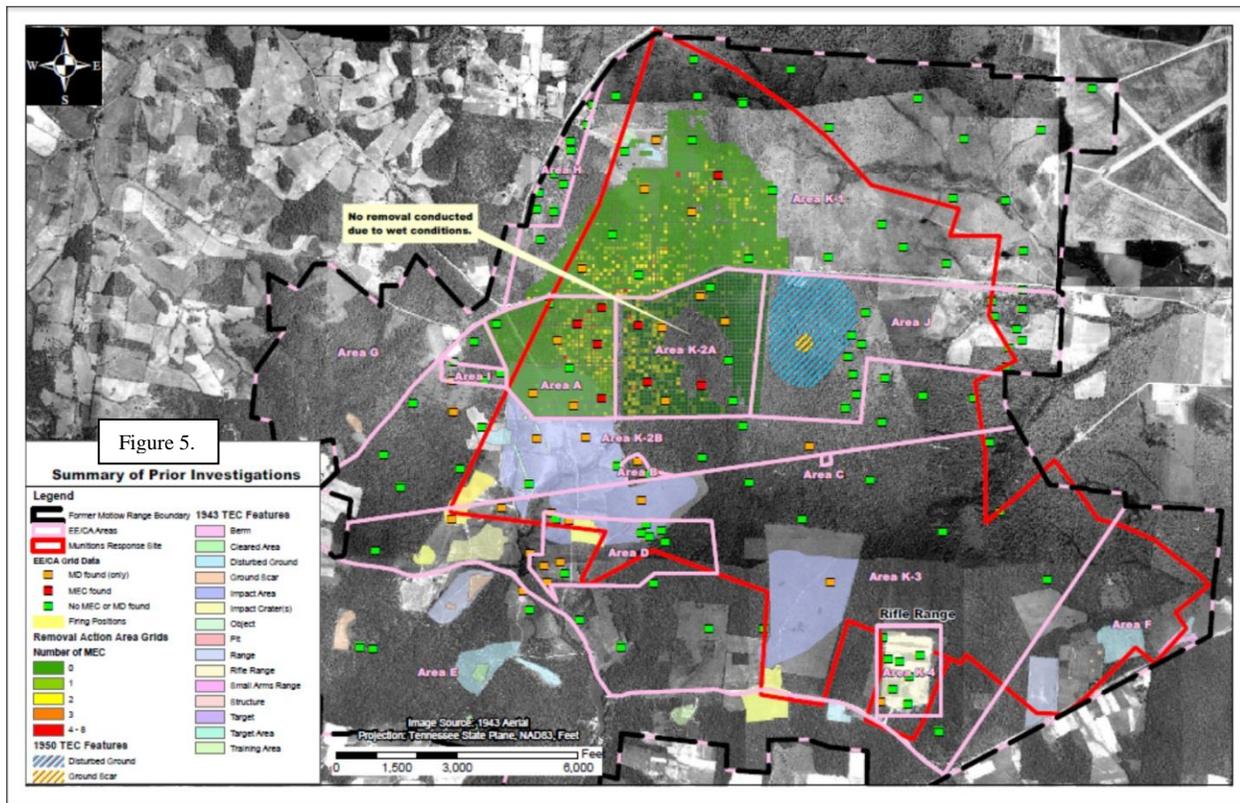
Figure 5. Summary of Prior Motlow Site Investigations

1995 Removal Action (Area A). In 1995, a removal action was performed within Area A, where the Motlow State Community College (MSCC) was building new library, nursing, and technology buildings, and some additional areas associated with the support of those buildings (covering approximately 14 acres). The clearance was conducted to 4 feet below ground surface (bgs) and revealed nine UXO, all of which were related to 37-mm projectiles. In addition, 722 anomalies were investigated in Area C, adjacent to a roadside park. This clearance was conducted to 6 inches bgs over 1 acre; no UXO were discovered within Area C.

1998 Engineering Evaluation/Cost Analysis Report. An engineering evaluation and cost analysis (EE/CA) was completed for the former Motlow Range in 1998. The EE/CA investigated 2797 anomalies detected within 142 grids (most of which were 100-foot x 100-foot, although some grids in wooded areas and were 50 x 50 feet). Nine UXO items were discovered during this investigation (Figure 5 shows the grids in which these items were found). Areas A, K-1, and K-2a were determined to be those areas where a risk of exposure to UXO existed; Areas C, E, and H were recommended for no further action; and the rest of the areas prescribed a minimal risk of exposure to UXO (Parsons 1998).

2002 Removal Action (Area A, K-1 and K-2a). A removal action was performed in 2002 to address the areas determined during the EE/CA that may contain UXO (i.e., Areas A, K-1, and K-2a). During the removal action, Area A was surveyed and flagged; however, the area was found to have an unexpectedly high anomaly density and removal actions in that area were postponed, being conducted under a separate effort in 2003 (see below). The removal action to

6 inches below surface was performed within 293 grids in Area K-1 (approximately 67 acres), where 33 UXO and 247 pounds of munitions debris were removed (Figure 5).

2003 Removal Action (MSCC parcel). A removal action also was performed on the MSCC parcel (approximately 180 acres) in 2003. Over 30,000 anomalies were investigated; 317 UXO were found (primarily 37-mm projectiles), and 1400 pounds of munitions debris were removed. Each of the 787 grids passed quality control (QC) and quality assurance (QA) inspection (ZAPATA Engineering 2004).

2004 Historic Photograph Analysis Report. In 2004, a Geographic Information System (GIS)-based historical photographic analysis was completed by the U.S. Army Engineer Research and Development Center's Topographic Engineering Center (TEC). This analysis interpreted black and white, vertical aerial photography spanning selected years from 1943 to 1950. Selected features such as impact areas, disturbed ground, firing points, and other indications of military training were noted (Figure 5).

2007 Removal Action (Area K-1 and K-2a). A third removal action was performed in 2006 and 2007 over a portion of Area K-1 (431 acres) and Area K-2a (273 acres). The removal action cleared to 6 inches bgs, detecting 40,147 anomalies and recovering 367 UXO items, mostly associated with 37-mm projectiles (355 items); however, three 3-inch Stokes mortars, two 155-mm projectiles, and a 2.36-inch rocket also were found during this operation (ZAPATA Engineering 2007).

4.3   CONCEPTUAL SITE MODEL

Prior to the RI study, a preliminary Conceptual Site Model (CSM) was prepared to facilitate the development of a technical approach for the RI at the Motlow Range Complex. The CSM describes the characteristics of the MRS, including the known or suspected types of MEC present, anticipated locations and distribution of MEC contamination, possible exposure media, receptors, and potentially complete contaminant exposure pathways. The CSM is a "living document" updated throughout the project as assumptions change and new data becomes available. The initial CSM was based on current site knowledge obtained from available site documents. The 3646-acre Range Complex MRS was divided into three general areas for this initial CSM: Area 1 (Prior Removal Action Areas), where MEC may have been present but have now been removed; Area 2 (Former Range Areas and Firing Points), where there is strong evidence of prior munitions use so MEC are potentially present; and Area 3 (Buffer Areas and Small Arms Ranges), where there is minimal or no evidence of MEC presence. The areas are shown on Figure 6 and are described further below.

For purposes of this CSM and the RI/Feasibility Study, a "MEC contaminated" area is defined as being affected by concentrated munitions use, which is characterized by both high subsurface anomaly density and the presence of MEC and/or large quantities of munitions debris.

The figure contains a legend and an embedded table:

Investigation Areas	Acres (approximate)	Past Use/Proposed Approach
Area 1	717	Prior MEC removal action areas. MC Sampling only (Figure 5).
Area 2a	875	Former Range Areas (Probable Impact Areas with no Prior Removal). Perform DGM surveys (transects & grids), Intrusive investigation & MC sampling
Area 2b	5.5	Evidence of possible past use as artillery firing point. Perform 100% DGM, Intrusive investigation & MC sampling (Figure 4).
Area 3a	1,979	Remaining Area including buffers (No evidence of MEC Presence). Perform DGM surveys (grids), intrusive investigation & MC sampling.
Area 3b	67	Small Arms Range Areas. MC Sampling only.

Conceptual Site Model and Proposed Investigation Areas

Legend
- Munitions Response Site
- Proposed Investigation Areas
- Proposed DGM Transects*

Parcels
- Other Landowners
- Cumberland Springs

* The location of actual transects will be based on field conditions, parcel boundaries, and areas of interest identified in the field.

Image Source: Bing Maps Aerial 2012
Projection: Tennessee State Plane, NAD83, Feet

0 1,000 2,000 4,000 Feet

Figure 6. Conceptual Site Model and Proposed Investigation Areas

Area 1: Prior Removal Action Areas. These two parts of the MRS include the areas that were subject to previous removal actions in 1995, 2002, 2003, 2006, and 2007. These areas were previously designated in various historical documents as Areas A, C, K-1, and K-2a. Area 1 incorporates areas with known historic MEC impacts and evidence of prior concentrated munitions use. The land uses in Area 1 are primarily a combination of forestry and wildlife management, though the formerly designated Area A is largely occupied by Motlow State Community College (MSCC). Based on these land uses, potential receptors include MSCC staff and students, loggers, hunters, and site visitors, as well as ecological receptors. Area 1 includes grids within formerly designated Areas A, C, K-1, and K-2a where MEC have been found, and there is a high degree of confidence regarding the past use of Area 1 (i.e., target/impact area). The prior removal actions were completed to a depth of at least 6 inches bgs and, while unknown, it is considered unlikely that MEC remain at depths greater than 6 inches bgs. The 6-inch clearance depth was identified in the EE/CA action memorandum based on the characterized MEC hazards and exposure pathways. QA was conducted and passed by USACE over the removal action grids. The forms did not indicate that the QA inspection was limited to 6 inches; therefore, it is understood that the grids were cleared to depth of detection. Because of these previous removals, it is anticipated that the MEC exposure pathways in Area 1 are currently incomplete, and no additional MEC clearance will be necessary within Area 1.

Area 2: Former Range Areas and Firing Points. Area 2 consists of portions of the Range Complex MRS that were not addressed during the previous removal actions but, based on known historic use and other available data (e.g., TEC photographic analysis), are either known or suspected to contain MEC and/or munitions constituents (MC) resulting from artillery or mortar training. For purposes of the initial CSM, Area 2 was subdivided into two parts, Areas 2a and 2b, based on the prior use of the area (i.e., impact areas or firing points).

Area 2a encompasses parts of the MRS identified in the 1994 ASR and TEC photographic analysis as potential target or impact areas related to the former anti-tank and mortar ranges (Figure 6). The land uses in Area 2a are primarily a combination of forestry and agriculture, though there are small areas of residential land use. Based on these land uses, potential receptors include residents, commercial workers, loggers, hunters, and site visitors, as well as ecological receptors. The CSM for Area 2a assumes that the major concentration of MEC and munitions debris (i.e., "MEC contamination") will be focused on at least one former target location in a circular or elliptical pattern. The use of these former target or impact areas means that any MEC found are most likely to be UXO. The anomaly density at these target locations is anticipated to be significantly elevated above background levels, while the areas outside the target locations are anticipated to have lower anomaly density and be unaffected by concentrated munitions use.

Area 2b includes several areas that were indicated to be possible firing positions, none of which have been investigated to date. The land uses in Area 2b are primarily forestry and agriculture. Based on these land uses, potential receptors include agricultural workers, loggers, hunters, and site visitors, as well as ecological receptors. The CSM for Area 2b assumes that the major concentration of MEC and munitions debris (i.e., "MEC contamination") would be found in burial pits or trenches in the vicinity of the former firing points. Based on current site data and recorded discoveries, the munitions that might be present at the former firing positions are 37-mm projectiles, 60-mm mortars, 3-inch Stokes mortars, 81-mm mortars, 155-mm projectiles, and 2.36-inch rockets. The possible presence of these munitions makes the MEC exposure pathways in Area 2b potentially complete, which means that potential MEC hazards exist within Area 2b; however, the nature of these areas (burial pits) means that these hazards are only anticipated to be in the subsurface.

Area 3: Buffer Areas and Small Arms Ranges. These portions of the Range Complex MRS include areas that were not investigated extensively during the previous EE/CA but, based on known historic use and other available data (e.g., EE/CA and TEC photographic analysis), are considered unlikely to contain residual MEC. For the initial CSM, Area 3 has been subdivided into Areas 3a and 3b based on their prior use (i.e., range buffer areas or small arms ranges).

Area 3a incorporates the buffer areas bordering Areas 1 and 2 (Figure 6). Some of these areas were subject to investigation during the 1998 EE/CA, at which time they were largely concluded to present a minimal risk of exposure to UXO. The land uses in Area 3a are primarily forestry and agriculture, though small areas of residential land use are present. Based on these land uses, potential receptors include residents, commercial workers, agricultural workers, loggers, hunters, and site visitors, as well as ecological receptors. The CSM for Area 3a assumes that there are no areas affected by concentrated munitions use present.

Area 3b comprises several areas that were associated with former small arms ranges at the Range Complex MRS (Figure 6). The land uses in Area 3b are forestry and agriculture. Based on these land uses, potential receptors include agricultural workers, loggers, hunters, and site visitors, as well as ecological receptors. Intact small arms ammunition are not MEC, so no significant explosive hazards would be present at these former ranges.

4.4   SITE GEOLOGY

There are three soil associations in the former Motlow Range. The first and largest is the Dickson-Mountview-Armour association. It is composed of gently rolling and rolling, well drained and moderately well drained, silt loams on broad ridge caps, and nearly level, poorly drained silt loams in depressions, and near the head of drainage ways. The Dellrose- Mimosa-Rock Outcrop association consists of steep, cherty, well drained upland soils with brown, cherty, silty clay loam sub soils greater than 6 feet to bedrock; and steep, well drained, cherty upland soils that have yellowish brown, firm, plastic subsoils 2 to 5 feet to bedrock; and areas of outcropping limestone. The third is the Bodine-Mountain-Ennis association. It consists of deep, well drained, silty soils on steep hillsides leading to narrow cherty bottom soils along meandering drainage ways.

4.5   MUNITIONS CONTAMINATION

The following summary was derived from the draft work plan prepared by Parsons. Multiple MEC and munitions debris items were previously recovered from the project site, indicating there is the potential for additional items to be present. There are several potential MEC items that might be found at the former Motlow Range including anti-tank rifle grenades, 37-mm projectiles, 75-mm projectiles, 105-mm projectiles, 60-mm mortars, 3-inch Stokes mortars, 81-mm mortars, 155-mm projectiles, and 2.36-inch rockets. A list of the MEC known or suspected to be present at the project site is presented in Table 2.

Table 2. Munitions Potentially Present at the Former Motlow Range, Chemical Compositions, and MCs

Munitions Type/Model	Composition (Case and Filler)	MC Selected for Analysis [1]
Grenade, Rifle, Anti-Tank, M9A1	**Munition Case: Sheet Steel -** Carbon, Iron, Manganese, Phosphorus, Sulfur **Munition Filler:** Pentaerythritol Tetranitrate (PETN), Tetryl, Trinitrotoluene (TNT) **Booster:** Tetryl **Primer[4]:** Antimony Sulfide, Barium Nitrate, Copper, Iron, Lead, Lead Azide, Lead Styphnate, Tetrazene, Zinc	**Metals** N/A **Explosives** As a conservative measure, a full explosives panel will be analyzed
Rocket, 2.36-inch, HEAT (M6)	**Munition Case: Sheet Steel -** Carbon, Iron, Manganese, Phosphorus, Sulfur **Rocket Motor:** Barium Nitrate, Diazodinitrophenol, Nitrocellulose, Nitroglycerin, Potassium Chlorate, Potassium Nitrate, Potassium Perchlorate **Warhead:** Iron, PETN, TNT **Fuze:** Iron, Lead Azide, PETN (Pentaerythritol Tetranitrate), Tetryl	**Metals** Barium **Explosives** As a conservative measure, a full explosives panel will be analyzed

Munitions Type/Model	Composition (Case and Filler)	MC Selected for Analysis [1]
Small Arms General: **Cartridge, .30 caliber (includes carbine)**	**Cartridge case: Copper Alloy** – Copper, Iron, Lead, Zinc **Propellant:** Calcium Carbonate, Copper, Dibutylphthalate, Diphenylamine, Dinitrotoluene[3], Ethyl Centralite, Lead, Iron, Nitrocellulose[2], Nitroglycerin, Potassium Nitrate, Sodium Sulfate, Zinc **Primer[4]:** Aluminum Powder, Antimony Sulfide, Barium Nitrate, Copper, Iron, Lead, Lead Styphnate, Pentaerythritol Tetranitrate (PETN), Tetrazene, Zinc **Projectile**: Antimony, Carbon, Copper, Iron, Lead, Manganese, Silicon, Sulfur, Zinc **Tracer[5]:** Barium Peroxide, Calcium Resinate, Magnesium Powder, Polyvinyl Chloride, Strontium Nitrate, Strontium Oxalate, Strontium Peroxide, Zinc Stearate	**Metals[3]** Antimony, Copper, Lead **Explosives [4]** A full explosives panel will be analyzed
Small Arms General: **Cartridge, .45 caliber**	**Cartridge case: Copper Alloy** – Copper, Iron, Lead, Zinc **Propellant:** Diphenylamine, Dinitrotoluene[3], Nitrocellulose[2], Nitroglycerin, Potassium Nitrate, Potassium Sulfate **Primer[4]:** Antimony Sulfide, Barium Nitrate, Calcium Silicide, Copper, Iron, Lead Styphnate, Lead Thiocyanate, Nitrocellulose[5], Pentaerythritol Tetranitrate (PETN), Potassium Chlorate, Tetrazene, Trinitrotoluene (TNT), Zinc **Projectile**: Antimony, Carbon, Copper, Iron, Lead, Manganese, Phosphorus, Silicon, Sulfur, Zinc **Tracer[5]:** Barium Peroxide, Calcium Resinate, Magnesium, Strontium Nitrate, Strontium Oxalate, Strontium Peroxide, Zinc Stearate	**Metals[3]** Antimony, Copper, Lead **Explosives [4]** A full explosives panel will be analyzed
Small Arms General: **Cartridge, .50 caliber, Machine Gun**	**Cartridge case: Brass** – Copper, Zinc **Propellant:** Calcium Carbonate, Dibutylphthalate, Diphenylamine, Dinitrotoluene[3], Nitrocellulose[2], Nitroglycerin, Potassium Nitrate, Potassium Sulfate, Sodium Sulfate **Primer[4]:** Aluminum Powder, Antimony Sulfide, Barium Nitrate, Calcium Silicide, Copper, Iron, Lead, Lead Styphnate, Lead Thiocyanate, Potassium Chlorate, Pentaerythritol Tetranitrate (PETN), Tetrazene, Zinc **Projectile**: Antimony, Carbon, Copper, Iron, Lead, Manganese, Molybdenum, Sodium Carbonate Monohydrate, Silicon, Sulfur, Zinc **Tracer[5]:** Barium Peroxide, Calcium Resinate, Magnesium Powder, Polyvinyl Chloride, Potassium Perchlorate, Strontium Nitrate, Strontium Oxalate, Strontium Peroxide, Zinc Stearate	**Metals[3]** Antimony, Copper, Lead **Explosives [4]** A full explosives panel will be analyzed **Miscellaneous** Perchlorate[6]
Shell, 37-mm, Fixed, High Explosive (HE), Mk II	**Cartridge case: Copper Alloy** - Copper, Iron, Lead, Zinc **Propellant:** Dibutylphthalate, Dinitrotoluene[3], Diphenylamine Nitrocellulose[2], Nitroglycerin, Potassium Chlorate, Potassium Nitrate, Sulfur **Primer[4]:** Antimony Sulfide, Barium Nitrate, Lead Thiocyanate, Trinitrotoluene (TNT) **Projectile/Rotating Band: Steel/Copper Alloy** - Carbon, Copper, Iron, Lead, Manganese, Phosphorus, Sulfur, Zinc **Projectile Filler:** Trinitrotoluene (TNT) **Fuze, Projectile, Base Detonation, M38A1:** Carbon, Iron, Manganese, Phosphorus, Sulfur, Tetryl **Fuze Primer[4]:** Antimony Sulfide, Lead Azide, Potassium Chlorate	**Metals** Copper, Zinc **Explosives** As a conservative measure, a full explosives panel will be analyzed

Munitions Type/Model	Composition (Case and Filler)	MC Selected for Analysis [1]
Shell, 75-mm, Fixed, Shrapnel, MkI	**Cartridge Case: Copper** - Copper, Iron, Lead, Zinc **Propellant:** Dibutylphthalate, Dinitrotoluene[3], Diphenylamine, Nitrocellulose[2], Nitroglycerin, Potassium Nitrate, Sulfur **Primer[4]:** Antimony Sulfide, Barium Nitrate, Lead Thiocyanate, Potassium Chlorate, Potassium Nitrate, TNT (Trinitrotoluene) **Projectile: Steel** - Carbon, Iron, Manganese, Phosphorus, Sulfur **Projectile Filler:** Lead, Potassium Nitrate, Sulfur **Fuze, Powder Train Time, M1907: Brass** - Copper, Iron, Lead, Zinc **Fuze Filler:**, Potassium Nitrate, Sulfur **Fuze Primer[4]:** Antimony Sulfide, Mercury Fulminate, Potassium Chlorate	**Metals** Copper, Lead, Zinc **Explosives** As a conservative measure, a full explosives panel will be analyzed
Cartridge, 105-mm, High Explosive (HE), M1	**Cartridge Case: Copper Alloy -** Copper, Iron, Lead, Zinc **Propellant:** Dibutylphthalate, Dinitrotoluene[3], Diphenylamine, Lead Carbonate, Nitrocellulose[2] **Primer[4]:** Antimony sulfide, Carbon, Lead Thiocyanate, Potassium Chlorate, Trinitrotoluene (TNT) **Projectile/Rotating Band: Steel, Copper Alloy** - Carbon, Copper, Iron, Lead, Manganese, Phosphorus, Sulfur. Zinc **Projectile Filler: Amatol or Composition B or TNT** - Ammonium Nitrate, Cyclotrimethylenetrinitramine (RDX), Trinitrotoluene (TNT) **Fuze, Projectile, Point Detonating (PD), M51 Steel** - Carbon, Iron, Manganese, Phosphorus, Sulfur **Fuze Filler:** Tetryl **Fuze Primer[4]:** Antimony Sulfide, Carborundum, Copper, Lead Azide, Potassium Chlorate, Potassium Nitrate, Sodium Nitrate, Sulfur	**Metals** Copper, Zinc **Explosives** As a conservative measure, a full explosives panel will be analyzed
Projectile, 155-mm, High Explosive (HE), M101	**Projectile/Rotating Band: Steel/Copper Alloy** - Carbon, Copper, Iron, Lead, Manganese, Phosphorus, Sulfur, Zinc **Projectile Filler: Trinitrotoluene (TNT)** **Fuze, Projectile, Point Detonating (PD), M51 Steel** - Carbon, Iron, Manganese, Phosphorus, Sulfur **Fuze Filler:** Tetryl **Fuze Primer[4]:** Antimony Sulfide, Carborundum, Copper, Lead Azide, Potassium Chlorate, Potassium Nitrate, Sodium Nitrate, Sulfur	**Metals** Copper, Lead, Zinc **Explosives** As a conservative measure, a full explosives panel will be analyzed
Cartridge, 60-mm, High Explosive (HE), M49A2	**Propelling Assembly: Kraft Paper, Steel** - Iron, Manganese, Paper, Phosphorus, Sulfur, Zinc **Propellant:** Diethylphthalate, Nitrocellulose[2], Nitroglycerin, Potassium Nitrate **Primer[4]:** Antimony Sulfide, Lead Thiocyanate, Potassium Chlorate, Potassium Nitrate, Trinitrotoluene (TNT) **Projectile: Steel** - Carbon, Iron, Manganese, Phosphorus, Sulfur **Projectile Filler:** Trinitrotoluene (TNT) **Fuze, Point Detonating (PD), M52 series: Aluminum Alloy, Zinc Alloy** - Aluminum, Bismuth, Cadmium, Copper, Iron, Magnesium, Manganese, Nickel, Phosphorus, Silicon, Sulfur, Tin, Zinc **Fuze Filler:** Tetryl **Fuze Primer[4]:** Antimony Sulfide, Carborundum, Copper, Lead Azide, Potassium Chlorate, Zinc	**Metals** Aluminum, Copper, Zinc **Explosives** As a conservative measure, a full explosives panel will be analyzed

Munitions Type/Model	Composition (Case and Filler)	MC Selected for Analysis [1]
Shell, 3 inch, HE, Trench Mortar (Stokes Mortar), MkI and MkII	**Propellant Assembly: N/A** - Internal **Propellant:** Diphenylamine, Nitrocellulose[2] **Primer[4]:** Antimony Sulfide, Barium Nitrate, Lead Styphnate, Tetrazene **Projectile: Steel** - Carbon, Iron, Manganese, Phosphorus, Sulfur **Projectile Filler:** Tetryl, Trinitrotoluene (TNT) **Fuze: Steel** - Carbon, Iron, Manganese, Phosphorus, Sulfur **Fuze Filler:** Potassium Nitrate, Sulfur, Tetryl, Trinitrotoluene (TNT) **Fuze Primer[4]:** Copper, Mercury Fulminate, Phosphorus, Trinitrotoluene (TNT), Zinc	**Metals** N/A **Explosives** As a conservative measure, a full explosives panel will be analyzed
Cartridge, 81-mm, High Explosive (HE), M43A1B1	**Propelling Assembly: Kraft Paper, Steel** - Iron, Manganese, Paper, Phosphorus, Sulfur, Zinc **Propellant:** Diethylphthalate, Nitrocellulose[2], Nitroglycerin, Potassium Nitrate **Primer[4]:** Antimony Sulfide, Copper, Lead Thiocyanate, Potassium Chlorate, Potassium Nitrate, Trinitrotoluene (TNT), Sulfur, Zinc **Projectile: Steel** - Carbon, Iron, Manganese, Phosphorus, Sulfur **Projectile Filler: Trinitrotoluene (TNT) or Comp B** - Cyclotrimethylenetrinitramine (RDX), Trinitrotoluene (TNT) **Fuze, Point Detonating (PD), M52, M525: Aluminum Alloy** - Aluminum, Copper, Iron, Lead, Magnesium, Zinc **Fuze Filler:** RDX , (Cyclotrimethylenetrinitramine), Tetryl **Fuze Primer[4]:** Antimony Sulfide, Barium Nitrate, Lead Azide, Lead Styphnate, Tetrazene	**Metals** Aluminum, Copper, Zinc **Explosives** As a conservative measure, a full explosives panel will be analyzed

(1) MC selected for analysis are typically non-essential nutrient metals and indicative of known or suspected DOD munitions used at this area. MC not selected for analysis are essential nutrient metals, Semi-Volatile Organic Compounds (SVOCs) or materials that represent a very small percentage of the munitions weight. Lead was added to the analyte list at the request of the Project Team.

(2) Nitrocellulose is not considered toxic, has no risk-based screening values and there are no chemical analysis techniques that quantify nitrocellulose separately from the natural common essential nutrient nitrate. Based on this, nitrocellulose analysis will not be conducted during this SI.

(3) Dinitrotoluene products include: 2,4-and 2,6-dinitrotoluene; 2-Amino-4,6-dinitrotoluene; 2-and 3-nitrotoluene; 4-Amino-2,6-dinitrotoluene; 4-nitrotoluene.

(4) Primer materials represent a very small percentage of the munitions weight, therefore, primer constituents will not be analyzed for at this area (if a primer constituent is associated with a larger component of the munition it may be analyzed for).

(5) Tracer element materials represent a very small percentage of the munitions weight and is consumed while the projectile travels to the target, therefore, tracer element constituents will not be analyzed for at this MRS (if a tracer element constituent is associated with a larger component of the munition it may be analyzed for).

(6) Surface and ground water samples (if available) will be analyzed for perchlorate.

Source – Munitions information was supplied by the Munitions Items Disposition Action System (MIDAS) database, and USACE Range Operations Reports RO-05, RO-14, RO-15 and RO-17.

5   TEST DESIGN AND ANALYSIS PLAN

The performance objectives described in Section 3 that apply to the test design and data analysis plan can be grouped into the demonstration performed on Motlow site or the simulated site demonstration.

The test plan was set up to evaluate and demonstrate the several aspects of the VSP-RI module and to support the performance objectives outlined in Section 3. Different VSP-RI modules were applied to the three types of areas discussed below with both the transect design and data

visualization/analysis capabilities employed. We also simulated various ground-truth data sets varying the spatial TOI distribution across the site to evaluate the performance of transect and grid surveys.

5.1 Transect Design Options for Three Types Of Areas

During an RI, typically there are three types of areas encountered within an MRS.

- **Type-1 Areas**: Areas with known munitions use and suspected target areas
- **Type-2 Areas**: Areas with no clear target area discovery needs (outside of known target areas that have some potential munition use or areas with known munitions use but no clear target at which munitions were fired).
- **Type-3 Areas**: Areas that are presumptively clean but more evidence is required to support this claim.

The decision objectives and therefore survey and analysis objectives are different for each of these types of areas. The primary decision objectives that affect the survey design are listed in Table 3 for each type of area.

Table 3. Description and VSP-RI Objectives for Different Types of Areas

Type of Area	Description	RI Objectives
Type-1 Areas	Areas with known munitions use and suspected target areas	• Identify any target areas if they exist • Delineate those target areas • Estimate the number of anomalies or anomaly density • Explore the spatial anomaly distribution
Type-2 Areas	Areas with no clear target area discovery needs (outside of known target areas that have some potential munition use or areas with known munitions use but no clear target at which munitions were fired).	• Estimate UXO/acre (or MEC/acre or some other rate) or the number of possible UXO (or MEC or…) and show that we are confident that it is less than some pre-specified limit.
Type-3 Areas	Areas that are presumptively clean but additional evidence is needed to support this claim	• Show that you are X% confident that at least Y% of all possible transects of a prescribed length do not contain unacceptable items or, • Estimate TOI/acre (UXO/acre or MEC/acre or some other rate) or the total number of TOI and show that we are confident that it is less than some pre-specified limit.

5.1.1 Type-1 Area Demonstration (Area 2a)

For the Motlow site, the Type-1 area was designated as Area 2a in Figure 6. Based on previous studies, there was real potential for encountering target areas within Area 2a. In this area, the VSP transect design tools for target-area detection were recommended, and the contractor had already used those VSP tools to develop a proposed transect survey plan within their work plan. PNNL reviewed the VSP user parameter inputs used by Parsons for their proposed transect

survey design and found it adequate for the purposes of this VSP-RI demonstration and did not require any modifications to that proposed transect survey plan. The proposed transect design shown in Figure 7 was based on achieving a high probability (~90%) of traversing and detecting a 37-mm target area (~333-ft radius circular area) that has an average anomaly density that is approximately 100 anomalies/acre above a background of 20/acre with 3-foot wide transects. The VSP target area flagging and geostatisical mapping methods were employed using the actual course-over-ground and anomaly location survey results and are reported in Section 6.

Figure 7. Planned Transect Survey for the Type-1 Area (Area 2a)

5.1.2   Type-2 Area Demonstration (Area 3a)

The Type-2 Areas on this Motlow site are designated as Area 3a (~1940 acres) in Figure 6. Based on previous studies, there is no indication of target areas in these buffer areas and little, if any, munitions use. The contractor proposed using UXO Estimator to determine the survey acreage required to show that they are 90% confident that there are no more than 0.5 UXO/acre within this area. Based on this results in proposal, ~0.28% of the site must be surveyed (~4.6 acres). The contractor decided to perform grid surveys instead of transect surveys.

PNNL had concerns about employing grid surveys and believed that long transects would have greater likelihood of preserving the desired 90% confidence than grids. The contractors, USACE, and regulators were receptive to recommendations to augment their grid surveys with

additional transect surveys to support a comparison between the two survey approaches. Based on a preliminary analysis using the new VSP-RI module that was designed to support the decision objective for Type-2 areas, PNNL felt that the ~0.28% survey acreage would be sufficient for this demonstration. We felt that this survey coverage was conservative because no prior information or reliance on our VSP-RI Bayesian model was necessary.

PNNL recommended two possible transect survey approaches rather than a grid survey that would meet the design objective of 90% confident of showing that the TOI/acre is less than 0.5/acre. However, because of budgetary constraints, the complete proposed transect survey of ~0.28% survey coverage (4.6 acres) could not be attained. It was determined that we could still use the reduced survey results to explore the Bayesian and non-Bayesian options of this VSP-RI approach and still support the objectives of this demonstration (see Section 6).

PNNL originally proposed two survey options for Area 3a, which are discussed below. Both options provide for ~0.29% survey coverage (4.8 acres), and some right of entry exclusion zones were excluded from transect-survey possibilities. Note that the 0.29% and 4.8 acres is slightly higher than the calculated requirement because of the finite transect dimensions and random transect placement options. Option 1 uses equally-spaced, parallel transects that run across the entire site. Option 2 also uses parallel transects, but the placement is random and the transect lengths are roughly equal (except for narrow areas of the site). Initially Parsons was going to perform the transect surveys outlined in Option 1, but due to limited funding, they were only able to complete about every other transect (i.e., approximately half of the transects).

5.1.2.1   Proposed Option 1 – Parallel Transects With Equal Spacing

Figure 8 shows the option with equally spaced parallel transect placement with transects running across the length of Area 3a. Although the calculation results in 0.274% coverage, the actual survey coverage can vary due to the random start transect placement algorithm and the finite length of transects. Also, the transect dimension (10,000 feet long) is ignored for this transect placement option. The parameters used for this both Options 1 and 2 in VSP are shown in Table 4.
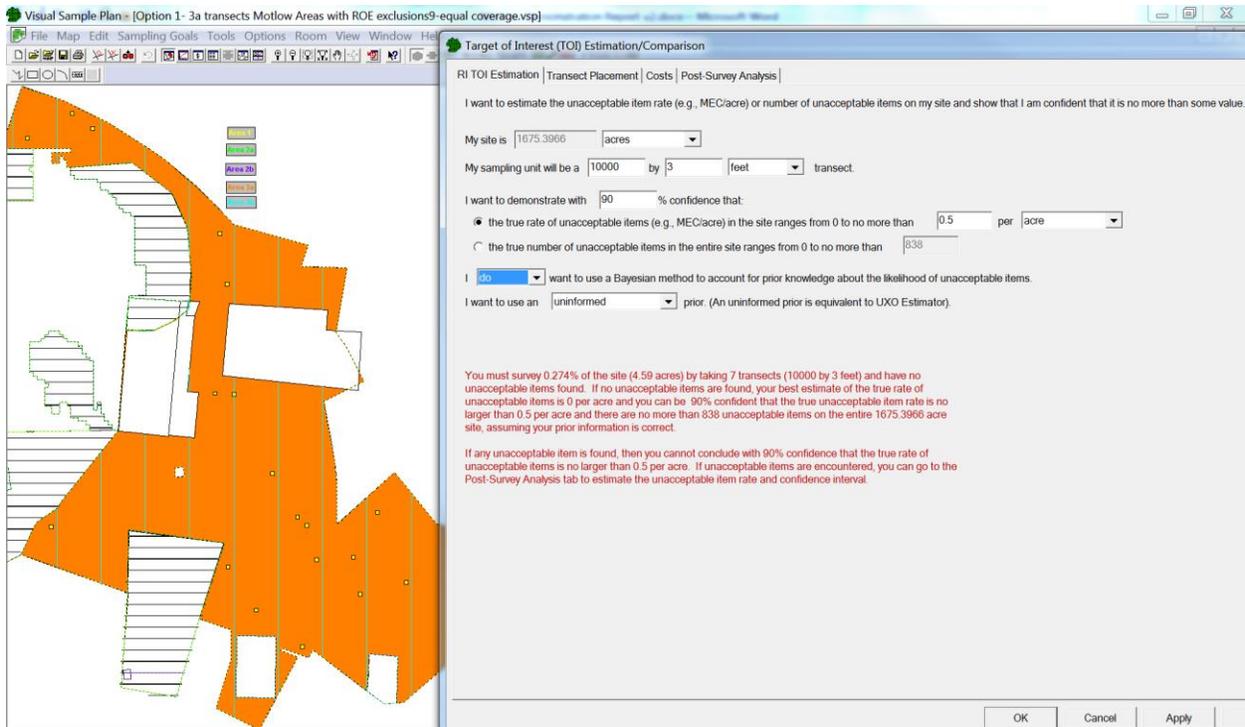
Figure 8. Proposed Option 1 Transect Design for Area 3a

Table 4. Summary of Design Parameters for Area 3a

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Estimate TOI Rate for a site and confidently demonstrate that the true rate is less than a pre-specified value
TARGET AREA AND TRANSECT INPUTS	
Type of Sampling Design	Transects
Transect Pattern	Parallel
Transect Width	3.281 feet
PROPOSED TRANSECT DESIGN	
Number of selected sample areas [a]	1
Specified site area	1675.40 acres
Upper bound for TOI rate	0.5/acre
Upper bound for number of TOI	838
Confidence required that upper bounds are not exceeded	90%
Total length of surveyed transects	12.12 miles
Area to be surveyed (area under the transects)	4.82 acres
Transect coverage	~0.29%

5.1.2.2 Proposed Option 2 – Parallel Transects Not Equally Spaced

Figure 9 shows the UXO Estimator equivalent option which employs random parallel transect sampling with 4000 feet by 1-meter transects placed within Area 3a.
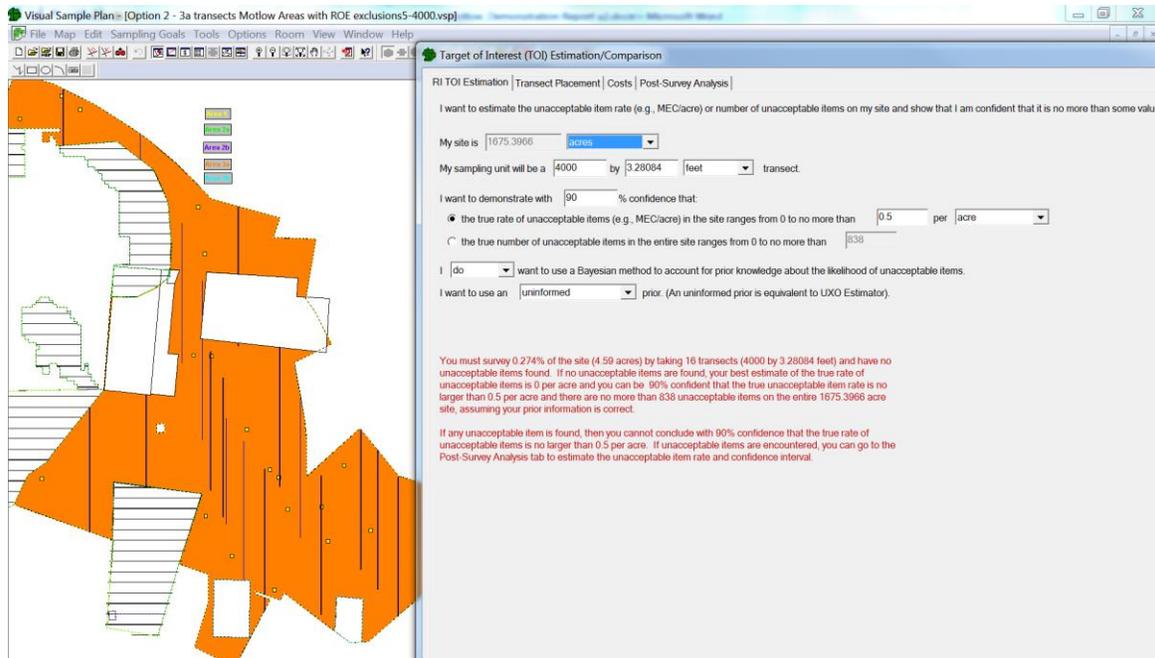
Figure 9. Proposed Option 2 Transect Design for Area 3a

5.1.3 Type-3 Area Demonstration

Although there are probably areas within Area 3a that might be considered Type-3 areas, in the Motlow site, all low-likelihood UXO areas are combined into one area. For an example of Type-3 areas in this document, we assumed that Area 3a was a presumptively clean site to illustrate the application of the methods when the objective is to demonstrate with X% confidence that no more than Y% of all possible transects contain unacceptable items. However, the survey requirements were not imposed for this demonstration and we will illustrate the survey requirements for varying assumptions. We also show what X%/Y% could be achieved given the actual and proposed amount of surveying for Area 3a.

5.2 Survey Unit Evaluation

A major unknown for survey sampling when the new VSP-RI modules or UXO Estimator is used is whether grids or transects are more appropriate. For example, if these tools suggest that for 90% confidence, 0.27% of the area must be surveyed. An extreme implementation would be to survey one large grid that covers 0.27% of the site. This is spatially unappealing, and the achieved confidence surely would not be 90% in most cases for expected spatial patterns of UXO. Long narrow transects are expected to preserve the confidence based on a previous PNNL study. But at some point, many small grids may also preserve the desired confidence. To study this, a simulation is performed within this demonstration (see Section 7.6).

To study the effects of grid vs. transect surveys, we use the Motlow site Area 3a boundary as the basis for a typical area size as well as a more complex boundary shape. Various spatial patterns and number of TOI are used on the site to create numerous ground truths. Then, the VSP-RI module for estimating and showing that UXO/acre is less than some criteria is repeatedly employed varying the VSP input parameters and the grid and transect survey options. Any

differences between the "as-designed" confidence and the "actually achieved" confidence are explored.

5.3 Survey Specifications

The survey sensors, calibration techniques, data collection procedures, quality control methods, and other logistical parameters were under the control of the Parsons contractor. These were specified within their work plan. PNNL did not make any alterations beyond the standard operating procedures typically deployed by the contractor. PNNL worked with the contractor and USACE staff to obtain the course-over-ground, anomaly location, and dig results files in an appropriate format for VSP ingestion.

6 DEMONSTRATION RESULTS AND ANALYSES

This demonstration project allowed an investigation of the performance of the VSP-RI sampling modules for the three scenarios outlined in Sections 2.1.1, 2.1.2, and 2.1.3.

6.1 Evaluation of the Type-1 Area (Area 2a)

For the Motlow site, the Type-1 area is designated as Area 2a in Figure 6. The primary objective was to detect and delineate target areas if they existed. The survey design outlined in Section 5.1 was performed by the contractor, and the actual course-over-ground transects and identified anomalies are shown in Figure 10.
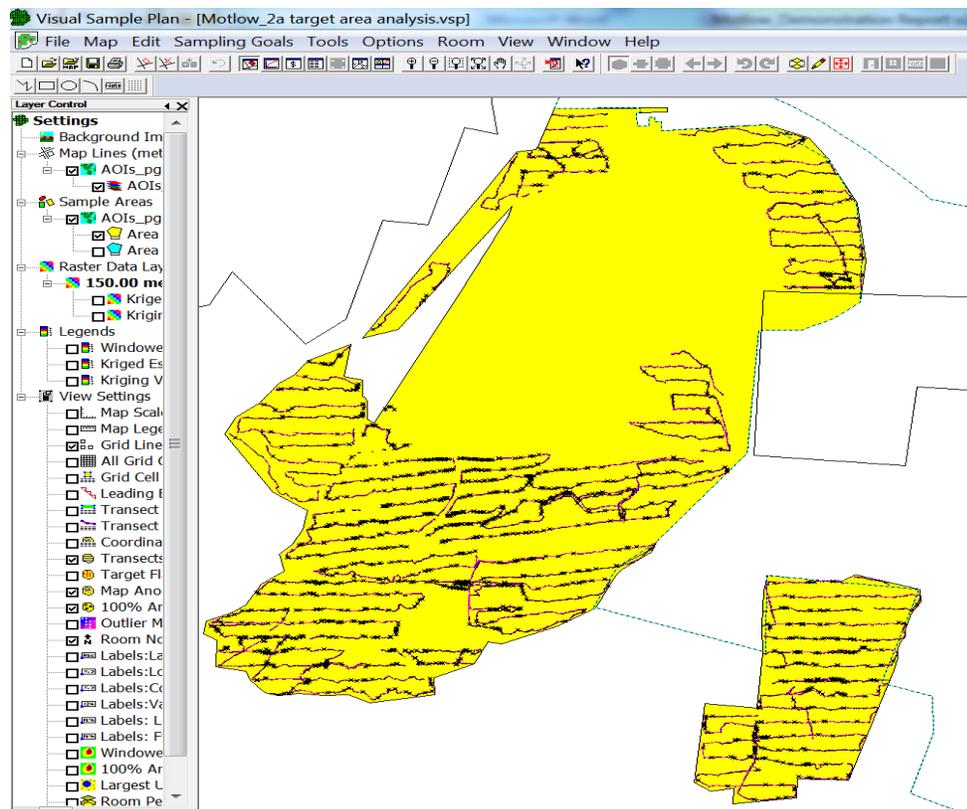
Figure 10. Area 2a Transects and Anomaly Locations

The VSP target area flagging and geostatisical mapping methods were employed using the actual course-over-ground and anomaly location survey results. Several potential target areas were identified and delineated. Figure 11 shows the results of the geostatistical analysis and delineates 13 possible target areas where the anomaly density appears to be significantly higher than background densities. Any area where the average kriged anomaly density was above 225/acre and at least 2 acres in size was identified and delineated. Several of these are clustered in the center of the larger portion of Area 2a south of the large unsampled area and may represent one large high-density area. Table 5 summarizes the attributes of the delineated areas.
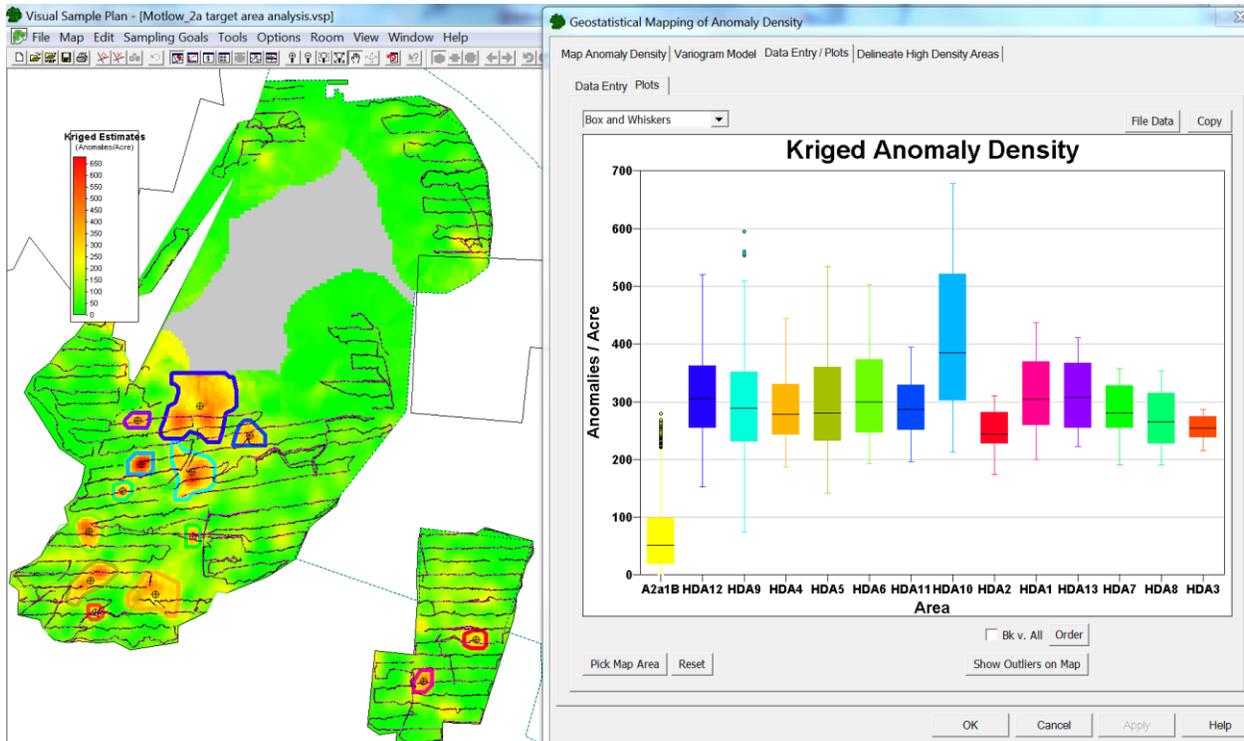
Figure 11. Geostatistical Mapping and Target Area Delineation for Area 2a

Table 5. Summary of delineated areas in Area 2a

Name	Creation Parameters	Size (acres)	Transect Area (acres)	Anomalies	Kriged Density (per acre)	Potential Anomalies
High-Density Area 1	Auto Krig: 225 / acre, 2 acres min	3.94	0.04	19	310.85	1224
High-Density Area 2	Auto Krig: 225 / acre, 2 acres min	4.17	0.04	10	252.54	1053
High-Density Area 3	Auto Krig: 225 / acre, 2 acres min	2.16	0.09	33	254.86	551
High-Density Area 4	Auto Krig: 225 / acre, 2 acres min	18.46	0.16	49	288.43	5323
High-Density Area 5	Auto Krig: 225 / acre, 2 acres min	13.05	0.13	46	302.09	3942
High-Density Area 6	Auto Krig: 225 / acre, 2 acres min	9.73	0.13	46	315.98	3074
High-Density Area 7	Auto Krig: 225 / acre, 2 acres min	3.55	0.08	32	286.38	1017

	acres min					
High-Density Area 8	Auto Krig: 225 / acre, 2 acres min	3.24	0.03	11	268.86	872
High-Density Area 9	Auto Krig: 225 / acre, 2 acres min	19.69	0.28	85	300.68	5921
High-Density Area 10	Auto Krig: 225 / acre, 2 acres min	6.02	0.04	18	419.87	2529
High-Density Area 11	Auto Krig: 225 / acre, 2 acres min	7.41	0.12	37	288.33	2137
High-Density Area 12	Auto Krig: 225 / acre, 2 acres min	46.18	0.23	82	314.20	14509
High-Density Area 13	Auto Krig: 225 / acre, 2 acres min	3.78	0.02	8	310.61	1175

This methodology in VSP for the objective of target-area detection and delineation within the RI stage performed as expected. The demonstration on Area 2a provides a good illustration of how this VSP module can be used to support this particular RI objective.

6.2   Evaluation of Type-2 Area (Area 3a)

In Section 4.3 we defined Area 3a, a set of buffer areas and small arms ranges not investigated in depth previously. Based on known historical use and available data, this area was considered unlikely to contain residual MEC and presents a minimal risk of exposure to UXO.

Sections 5.1.2.1 and 5.1.2.2 outlined initial transect survey schemes requested by PNNL. Because the option for north-south transects that traversed the entire site was operationally most feasible for the project team, they chose that option. Some portions of Area 3a could not be surveyed because of right of entry issues, and these areas were excluded from the total area acreage, which resulted in approximately 1610 acres in Area 3a. Unfortunately, because of unexpected difficulties and expenses encountered, the contractor was only able to perform every other transect that was proposed, resulting in 2.7 transect acres, 0.17% coverage, and 6.8 miles of transects. The original design called for 4.8 transect acres, 0.28% coverage, and 12.1 miles of transects. The actual course-over-ground transects and anomaly locations are shown in Figure 12
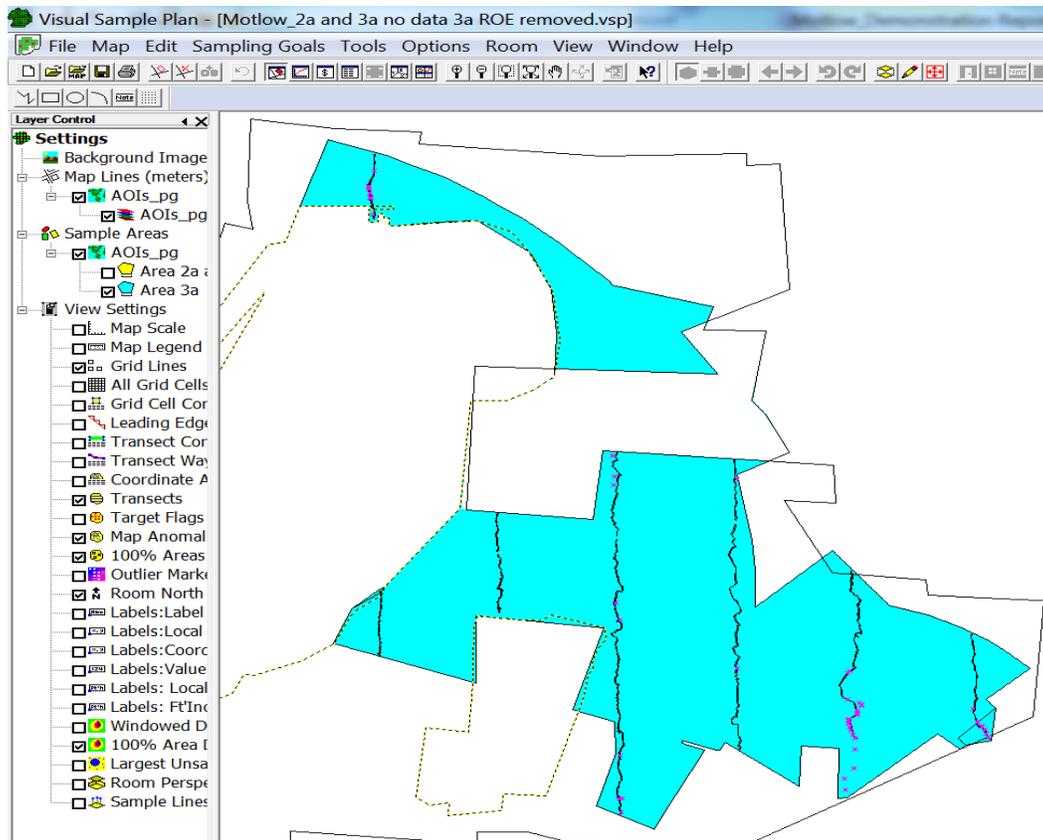
Figure 12. Actual Transects Performed and Anomalies Identified on Area 3a

6.2.1 Anomaly Dig Results and Estimation of TOI Per Acre

The primary objective of the RI for this Type-2 area was to estimate the TOI/acre and demonstrate with high confidence that it is less than 0.5/acre. Fifty-three anomalies were identified with the transect survey. Of these, the contractor was able to reacquire 43, which were dug and investigated to determine whether they were TOI. The investigation results for the 43 dug anomalies are shown in Appendix B. None of the dug anomalies from the limited number of transects in Area-3a were TOI.

As outlined in Section 2.1.2, within the VSP TOI/acre estimation and testing module, there are three possible options for whether and how to account for prior information: 1) Non-Bayesian, 2) Bayesian with an uninformed prior, or 3) Bayesian with an informed prior. In practice, there is usually little difference between the Non-Bayesian and uninformed Bayesian options, and the uninformed Bayesian method is equivalent to the UXO Estimator solution. The original design that required 4.8 transect acres and covered 0.28% of the site was devised using the uninformed Bayesian approach. However, as shown in Figure 13, using a reasonable informed prior allows the desired confidence to be achieved with only 2.37 transect acres and 0.147% coverage (ignore the transect length). This assumes that before surveying and digging one has at least 75% confidence that there are no more than 1000 TOI on this site and that there is equal likelihood of having greater or less than 499 TOI. Given the fact that from 100% surveys and anomaly digs within Area 1 where there were known target areas less than 800 TOI were found, this prior assumption seems very defensible for Area 3a.
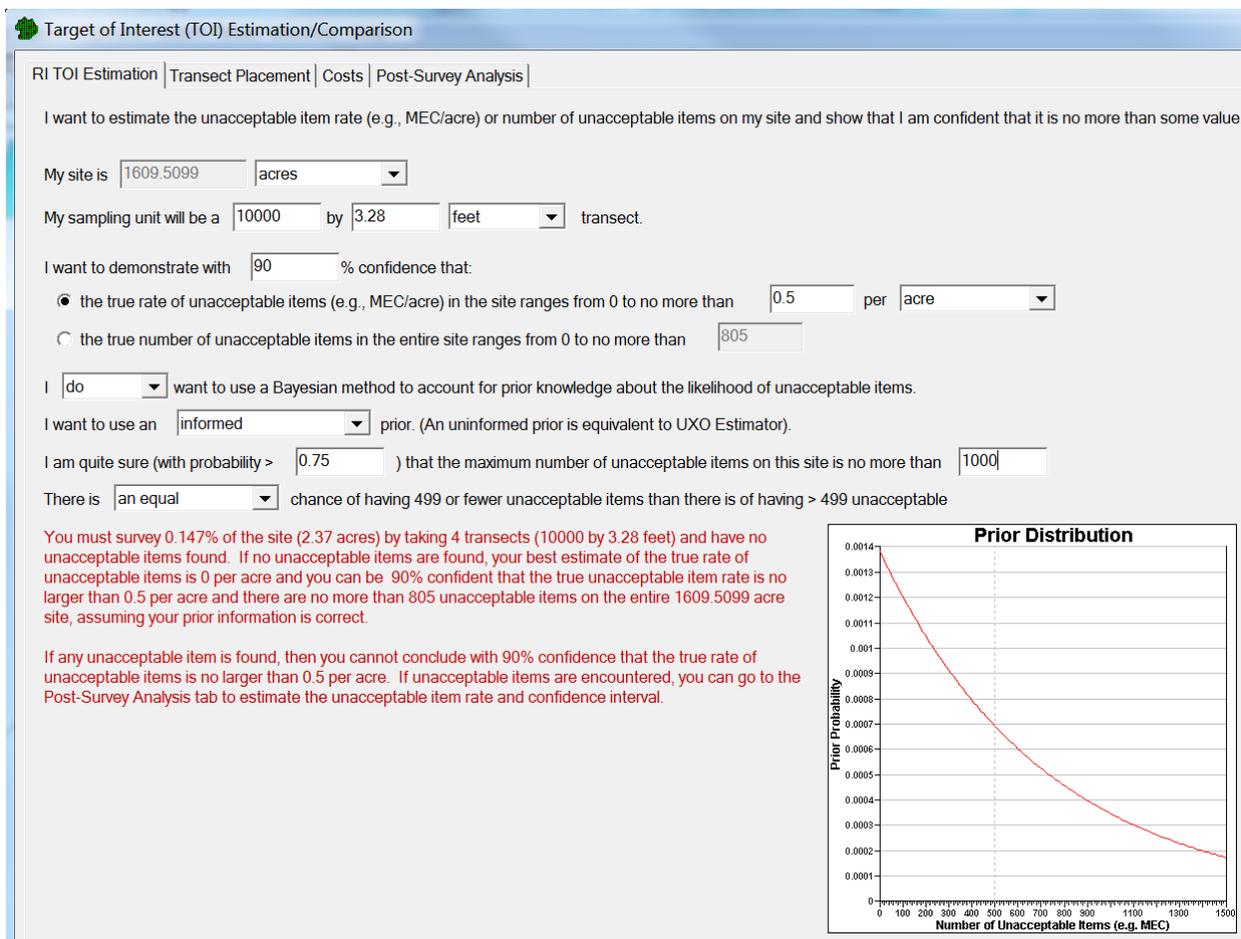
Figure 13. VSP Design Using a Conservative Informed Prior

Therefore, although the contractor could not perform all of the originally requested transects for Area 3a, they were able to perform a sufficient amount of surveying and digging to meet data quality objective requirements if the VSP informed prior approach is used. This demonstrates the benefits of reduced required survey acreage when the informed prior approach can be justified.

Using the VSP TOI/acre estimation and comparison module, the actual survey acreage can be input for Area 3a to determine whether using the informed Bayesian approach, one can be 90% confident that the true TOI/acre rate is less than 0.5/acre. Figure 14 shows that, with no TOI found for the 2.7 acreage surveyed (0.168% coverage), one can be 90% confident that the true rate is less than 0.466/acre. Alternatively, one can be 91.6% confident that the true rate is less than 0.5/acre. Based on this finding, the desired confidence goals were achieved for Area 3a by using the Bayesian model with defensible priors.

Figure 14. VSP Screenshot Showing Calculated Confidence for Achieved Survey Acreage

6.3   Evaluation of Type-3 Area (Area 3a revisited)

Although there was no area within this Motlow site that was designated as a presumptively clean site, Area 3a was considered as such for purposes of this demonstration report. Some stakeholders may want to make a different statement about the likelihood of TOI presence than that shown in Section 6.2 (TOI/acre is less than 0.5/acre). Another VSP module allows one to state that they are X% confident that at least Y% of all parcels of a specified size do not contain TOI if no TOI is found (see Section 2.1.3). Depending on the desired X% and Y% values, this module may require more survey acreage than the TOI/acre estimation/comparison module.

Suppose the stakeholders desired to develop a transect survey design for Area 3a that would allow them to state that they are 90% confident that no more than 3% of all possible ¼-acre parcels contain TOI. Assume they want to take use 4000-foot x 1-meter transects and are quite sure that there are not going to be more than 150 of the parcels that will contain TOI. Figure 15 shows that approximately 8.5 survey acres would be needed (0.53% coverage) and no TOI found in order to be 90% confident that no more than 3% of all possible parcels of concern contain TOI. Table 6 shows the survey acreage required for various input parameters.
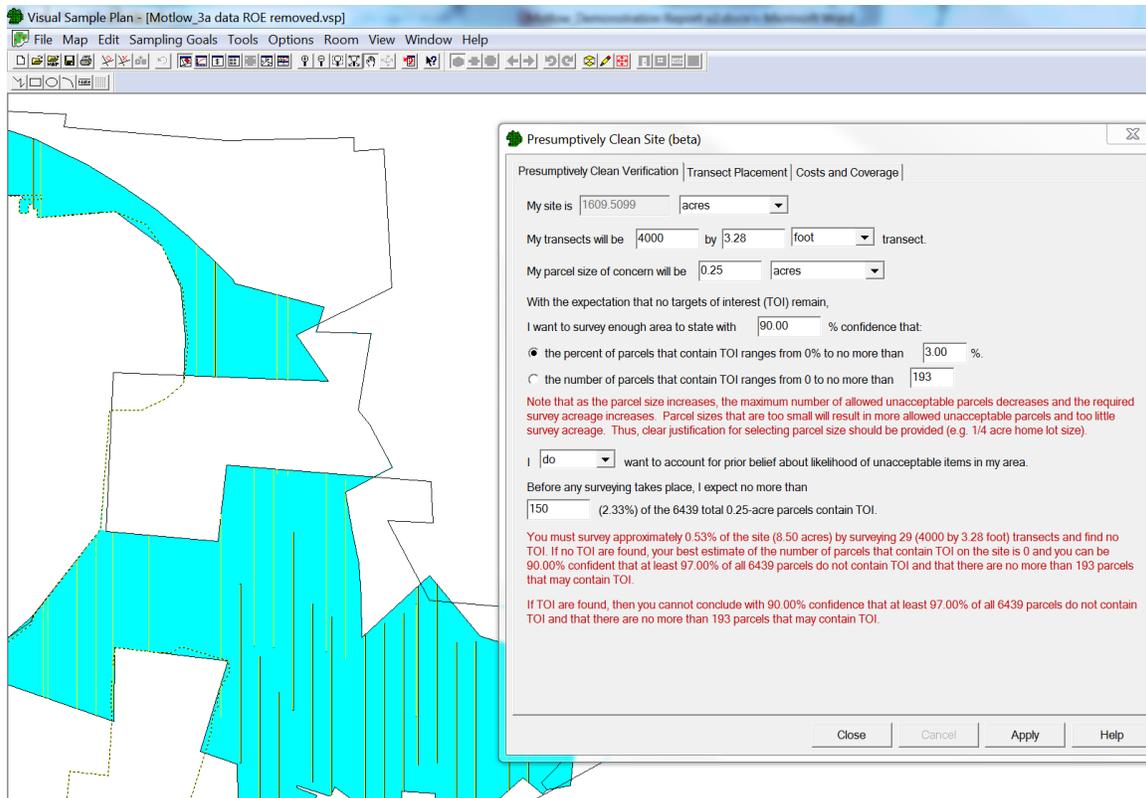
Figure 15. Example of VSP-RI Presumptively Clean Module Applied to Area 3a

Table 6. VSP Presumptively Clean Module Survey Requirements for Area 3a Assuming Various Input Parameters for a 1/4 Acre Parcel Size

Percent Confidence	Maximum Percent Parcels that May Contain TOI	Prior on Maximum Parcels w/ TOI	Required Survey Acreage	Percent Coverage
90%	5%	Unknown	11.25	0.70%
90%	5%	250	5.25	0.33%
90%	5%	200	3.50	0.22%
90%	3%	Unknown	19.0	1.18%
90%	3%	200	11.0	0.68%
90%	3%	150	8.5	0.53%
90%	1%	Unknown	56.5	3.51%
90%	1%	150	45.5	2.83%
90%	1%	50	24.75	1.54%
95%	5%	Unknown	14.75	0.92%
95%	5%	250	8.5	0.53%
95%	5%	200	7.0	0.43%
95%	3%	Unknown	24.5	1.52%
95%	3%	200	16.75	1.04%
95%	3%	150	14.0	0.87%
95%	1%	Unknown	73.0	4.54%
95%	1%	150	61.75	3.84%
95%	1%	50	41.25	2.56%

Bayesian Prior Used is the before surveying expected maximum number of ¼-acre parcels that could contain TOI in Area 3a.

Given the fact that the actual transect survey acreage on Area 3a was 2.7 acres and no TOI were found, one can determine the statistical statements that can be made for this X%/Y% objective. If no prior information is available, one can be 90% confident that no more than 20% of all ¼-acre parcels contain TOI, given the 2.7 acres surveyed. Because there were only approximately 700 TOI found on an adjacent area that contained target areas, it may not be unreasonable to assume that for Area 3a, no more than 700 of the ¼-acre parcels could contain TOI. Moreover, because no target areas are suspected in Area 3a, it may even be reasonable to assume that very few (say <200) of the parcels could contain TOI. Given the 2.7 acres surveyed, the achieved confidence and maximum percentages of the parcels that may contain TOI accounting for the prior information on the maximum number of TOI containing ¼-acre parcels (<700 or <200), are shown in Table 7.

Table 7. Achieved Confidence Given Actual Survey Results (2.7 acres surveyed and no TOI found) for Area 3a for a 1/4 Acre Parcel Size of Concern

Achieved Percent Confidence	Maximum Percent Parcels that May Contain TOI	Prior on Maximum Parcels w/ TOI
90%	20%	Unknown
90%	11.8%	700
90%	5.4%	200
<50%	5%	Unknown
62%	5%	700
88%	5%	200

6.4 Evaluation of Effects of Varied Dimension Transect Surveys and Grid Surveys on Confidence and Spatial Representation

The two designs performed in Area 3a do not provide enough information to validate the appropriateness of grids or varied transect dimensions. This evaluation is performed using simulated data in Section 7.6.

7 PERFORMANCE ASSESSMENT

The performance objectives for this demonstration are reiterated in Table 8 along with a brief performance assessment summary. All of the objectives of this demonstration were achieved except for the enhanced boundary delineation tools demonstration. Because of the unforeseen complexity of these new boundary delineation methods, these new tools in VSP were still under development when this demonstration was completed. It is anticipated that they will be illustrated in a future demonstration. Each of the performance objectives is discussed below.

Table 8. Performance Objectives and Evaluation Summary

Performance Objective	Metric	Success Criteria	Performance Assessment
1. Show application of VSP-RI modules for 3 types of areas	Application of the VSP-RI modules to three different types of areas within Motlow site.	• Well delineated target areas (see description) • Estimate an upper bound on TOI/acre • Acceptance of transect design input parameters.	VSP-RI Modules used successfully; target areas identified on Area 2a; TOI/acre shown to be <0.5 on Area 3a; Concurrence on transect design input parameters.
2. Experience for developing VSP-RI workflow process guidance.	Agreement within VSP-RI advisory committee of general workflow process.	Draft of VSP-RI workflow process developed.	Motlow Demo guided development of new VSP-UXO Expert Guide; Vetted with Advisory group.
3. Demonstrate usability of VSP-RI modules and identify needed improvements.	Contractor understanding/use of VSP-RI and list of recommended improvements.	Successful application of VSP-RI modules and minimal list of needed improvements.	VSP-RI modules successfully applied; Several improvements spawned by Motlow Demo.
4. VSP-RI module comparison with UXO Estimator	Cost of transects and simplicity of use. Demonstrate that VSP and UXO Estimator answers are same when same assumption is used.	VSP-RI survey acreage required is same as UXO estimator under certain conditions. VSP-RI shown to require less acreage under alternative assumptions.	VSP-RI TOI/Acre estimation/delineation module with unknown Bayesian prior shown equivalent to UXO Estimator; With informed prior, achieved desired confidence with reduced surveying.
5. Evaluate performance of transects vs. grids for UXO/acre estimation objective and spatial coverage index.	Desired confidence equals achieved confidences for simulations where UXO spatial density patterns and number of UXO are varied	Guidance to provide VSP-RI user help on selecting transect length and width.	1 m and 3 m wide transect consistently meet confidence objectives and are the most robust to TOI clustering. Grid surveying often did not meet desired confidence.
6. Compare the utility of different possible target area boundary delineation methods.	• Ease of use • Are boundaries, based on systematic transects, sufficiently bounding high-density areas for future remediation efforts?	• Boundary tools support cost estimation and associated uncertainty of remediation needs. • Boundary delineation results on synthesized sites are conservative (meet or exceed specified delineation objectives).	Complexity of new boundary delineation tools delayed availability for this demonstration; unachieved.

7.1   Objective 1 Assessment: Show Application of VSP-RI Modules for 3 Types Of Areas

As shown in Section 6, the VSP-RI modules were applied to Motlow areas and demonstrated to be effective in achieving the goals of the Motlow RI. For Area 2a (Type-1 area) where the objective was to identify and delineate any potential target areas, the application of the VSP generated transect survey design resulted in the identification and delineation of several potential target areas. This finding was consistent with the analysis performed by the Motlow RI contractor.

For Area 3a (Type-2 area), where the objective was to estimate TOI/acre and demonstrate that one can be 90% confident that the true TOI/acre rate was less than 0.5, the VSP generated transect survey design was developed. Because of funding and practical constraints, only about half of the as-designed transects were performed.   Yet, using the VSP-RI modules and reasonable Bayesian priors, the reduced survey acreage was sufficient to demonstrate that one can be 90% confident that the true TOI/acre rate is less than 0.5/acre.

Although the Motlow RI did not have a presumptively clean area (Type-3 area), Area 3a was used to demonstrate how one could have developed a transect survey design that allowed one to conclude that with X% confidence no more than Y% of all possible ¼-acre parcels contain TOI. This demonstration effectively showed how all three relevant VSP-RI modules can be applied during an RI process.

7.2   Objective 2 Assessment: Gain Experience for Developing VSP-RI Workflow Process Guidance

This Motlow demonstration provided real-world application experience for the VSP development team as we interacted with the project team at Parsons. This helped us formulate the content of a new VSP-UXO guide that any VSP user can launch. Figure 16 shows one of many screens within this VSP-UXO guide.   The purpose of this guide is to help the user determine which VSP modules are most appropriate for their particular use. This new expert guide will be publicly available in VSP 7.0 that will be released in March 2014.
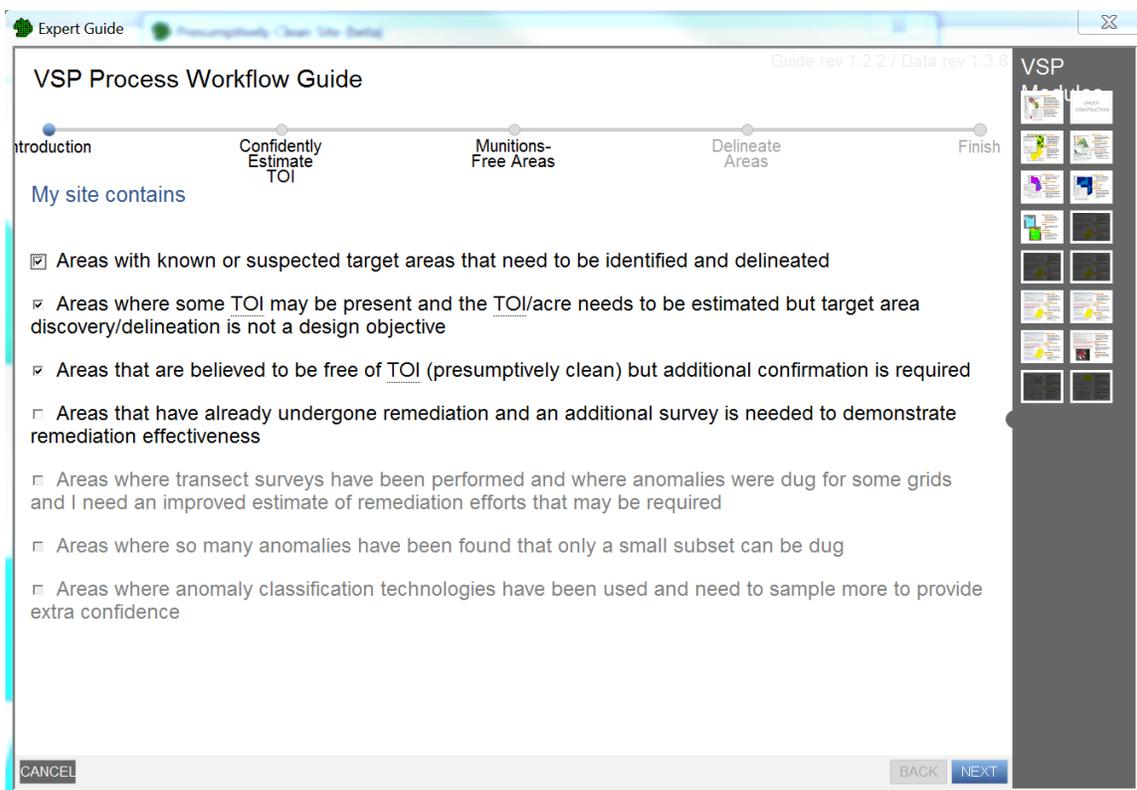

Figure 16. VSP-UXO Expert Guide Initial Page

7.3 Objective 3 Assessment: Evaluate Usability of VSP and Identify Needed Improvements

As we began this demonstration, the contractor had already used VSP to develop a transect survey design for Area 2a. They had no issues with using that module appropriately. For Area 3a, they used UXO Estimator to determine the required survey acreage and had already reached agreement with the stakeholders that they would perform grid surveys instead of transect surveys. However, they easily understood the VSP-RI module for estimating TOI/acre.

As we proceeded with this demonstration, although the VSP modules were easy to use and readily understood, the need for several modifications were identified and those were implemented to improve the modules. The major improvements are listed below.

- Transect placement options – Methods are being added to ensure unbiased spatial coverage of transects and deal with transects of a given length that would go beyond the boundaries of the area. Options for equally spaced transects that go the entire length of the areas also are being added to address practical constraints and operational efficiency of transect clearing and access issues.
- Parcel sizes for Presumptively Clean module – To avoid misuse and standardize the presumptively clean module (Type-3 area), we now force the user to specify a parcel size of concern and all statistical statements, and survey requirements are based on parcel size equivalent survey acreage.
- VSP-RI module organization – All the VSP modules that may be pertinent for an RI process were coupled together under one Sampling Goal in VSP called "Remedial Investigation (UXO)."
- Post-Survey TOI/Acre Estimation – A post survey analysis tab was added under the TOI/Acre Estimation and Comparison user dialog to calculate the estimated TOI/acre and upper confidence limit that was achieved based on actual survey acreage and number of TOI found which included the uninformed and informed Bayesian options.
- User dialog wording – Some of the wording on the user dialogs was changed to better ensure that user inputs would be correct and design/analysis outputs would be readily understood.
- Online help and automatic reports – The online help and automatically generated VSP reports were developed and added.

7.4   Objective 4 Assessment: VSP-RI Module Comparison with UXO Estimator

For the VSP-RI TOI/acre estimation and comparison module, when using uninformed priors, the required survey acreage from VSP is equivalent to the required survey acreage from UXO Estimator. Specific examples of VSP output compared to UXO output are shown in Table 9. The VSP output is rounded but as can be seen, these results are equivalent.

Table 9. VSP-RI Module Output Compared with UXO Estimator

Required Percent Confidence	Maximum True TOI/Acre Rate	Site Acreage	UXO Estimator Required Survey Acreage Output	VSP-RI Uninformed Prior Required Survey Acreage
90%	1/acre	1000	2.298	2.3
90%	0.5/acre	1000	4.586	4.59
90%	0.1/acre	1000	22.540	22.5
90%	1/acre	100	2.254	2.25
90%	0.5/acre	100	4.415	4.41
90%	0.1/acre	100	18.887	18.9
95%	1/acre	1000	2.989	2.99
95%	0.5/acre	1000	5.962	5.96
95%	0.1/acre	1000	29.226	29.2
95%	1/acre	100	2.923	2.92
95%	0.5/acre	100	5.705	5.7
95%	0.1/acre	100	23.841	23.8

7.5   Objective 5 Assessment: Evaluate Performance of Transects Vs. Grids for UXO/Acre Estimation Objective and Spatial Coverage Index

Sampling designs are always built on model assumptions, and it is often valuable to test the robustness of the designs to departures from their respective assumptions. In two previous documents, we have performed similar validations (Hathaway 2009, Pulsipher 2012). The previous two studies were developed to validate the verification sampling modules in VSP. For this study, we validate the RI TOI rate estimation and comparison sampling design. The primary difference between these two designs is the resulting confidence statements. For verification designs, the confidence statements answer questions about the percent of transects that do not contain TOI by calculating a fixed number of transects that must be surveyed. The RI TOI rate estimation and comparison sampling design provides confidence statements on the rate of TOI within the sample area and calculates an amount of area that must be surveyed.

When performing spatial sampling the two primary model assumptions that are generally evaluated are the spatial point (TOI) patterns and the sampling unit size. If there is no spatial TOI pattern (uniform TOI distribution throughout the sample area), any size and placement of sampling units is acceptable (see Figure 17). If the sampling unit is small enough, the confidence statements are quite robust to extreme spatial TOI patterns (few clusters with TOI tightly spaced around those clusters). In application, remedial investigation projects want each survey location (sampling unit or transect) to be as large as possible as it makes the survey work easier to complete. This work examines the sensitivity of the prescribed VSP confidence statements to variations in the spatial point patterns and sampling unit size.
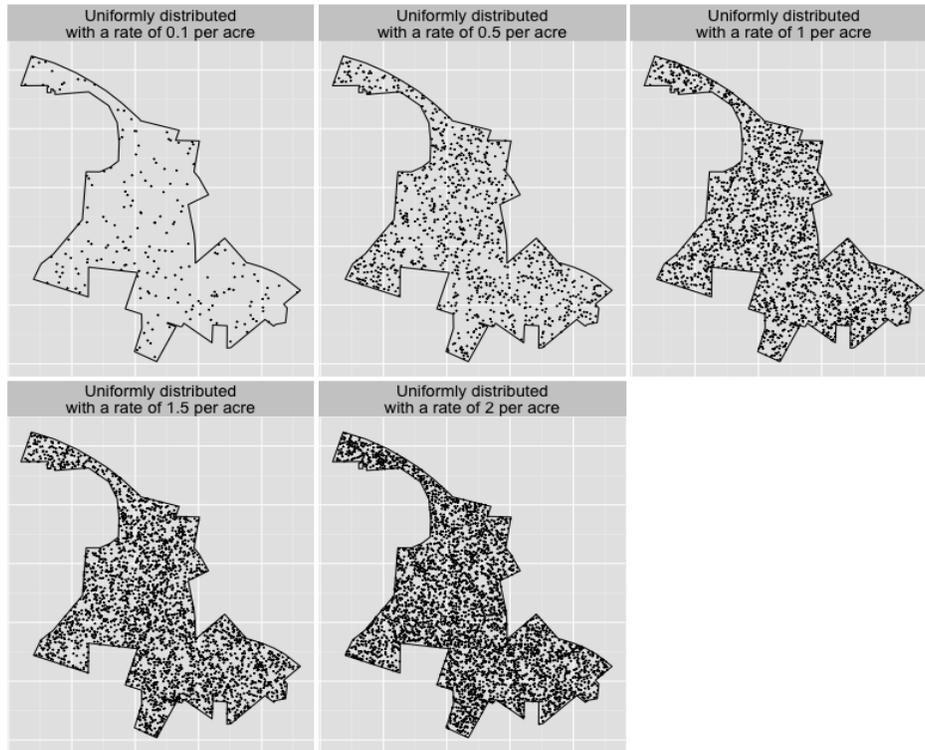
Figure 17. Uniform Point Patterns for the Five Different TOI per Acre Rates

We created 85 different TOI point patterns within the Motlow site boundaries. These 85 TOI patterns are a result of a combination of the TOI rate (0.1, 0.5, 1, 1.5, and 2 TOI/acre) and the type of clustering. The number of center points and the distance at which the points grouped around those center points defined the clustering. We used four different levels for the number of center points—10, 30, 60, 120, with four different levels for clustering around the center points—within 60 x 60 meters (0.9 acres), 125 x 125 meters (3.9 acres), 250 x 250 meters (15.4 acres), and 500 x 500 meters (62.8 acres) square area. Finally, a uniform distribution of TOI was generated for each TOI rate (see Figure 18).

The 16 different clustering patterns are also described by the max percent of area within the Motlow boundary where TOI points could be placed. For example, if there are 10 cluster locations where all points for each cluster are within a 0.9 acre footprint, then of the 1989 acres at Motlow at most 0.45% (9 acres) of the area has potential for TOI placement. Figure 18 and 19 show examples of the varied spatial TOI patterns for the 0.1 and 1 TOI rate per acre respectively with each spatial map labeled as to the max percent of area where TOI could be placed.

These 85 different TOI patterns were then used to validate the robustness of varied sampling unit dimensions on the confidence statements (90%, 95%, 99%, and 99.9%). We allowed the sampling unit to have dimensions of 50 x 50, 100 x 100, and 50 x 100 meters to represent grids. We also simulated transects with widths of 1, 3, and 6 meters with varied lengths of 50, 100, 500, 1000, and 3000 meters to make 18 different sampling unit dimensions. Additionally, we placed the transects using simple random sampling or systematic random sampling. The required survey acreages for the varied confidence and TOI rates are shown in Table 10. The

largest acreage is required from the 99.9/0.1 designs at 67.9 acres. The least required acreage results from the 90/2 designs at 1.2 acres.
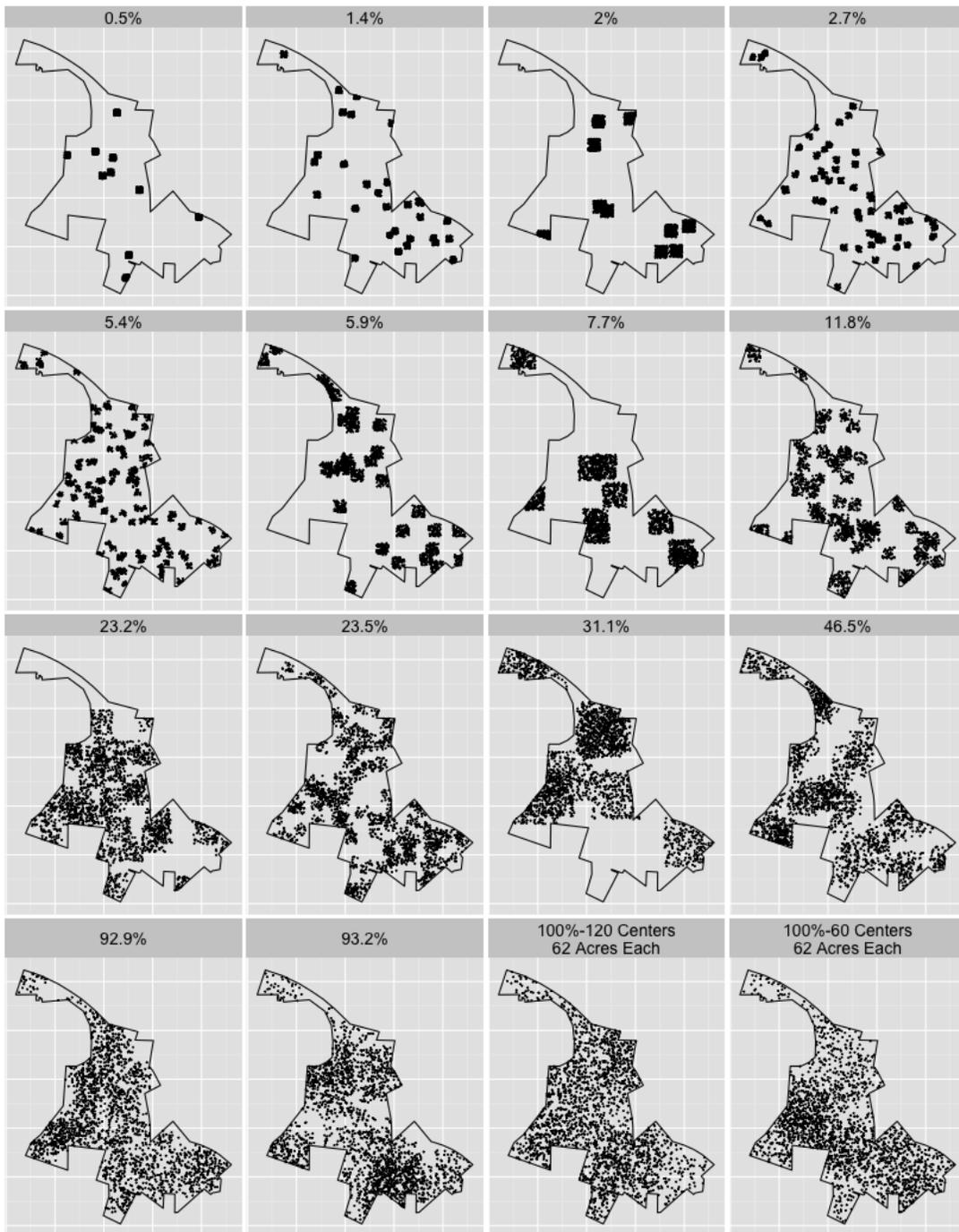
Figure 18. The 16 TOI Spatial Point Patterns Using a Rate of 1 TOI Per Acre Used to Evaluate the Confidence Performance for Different Sampling Unit Dimensions
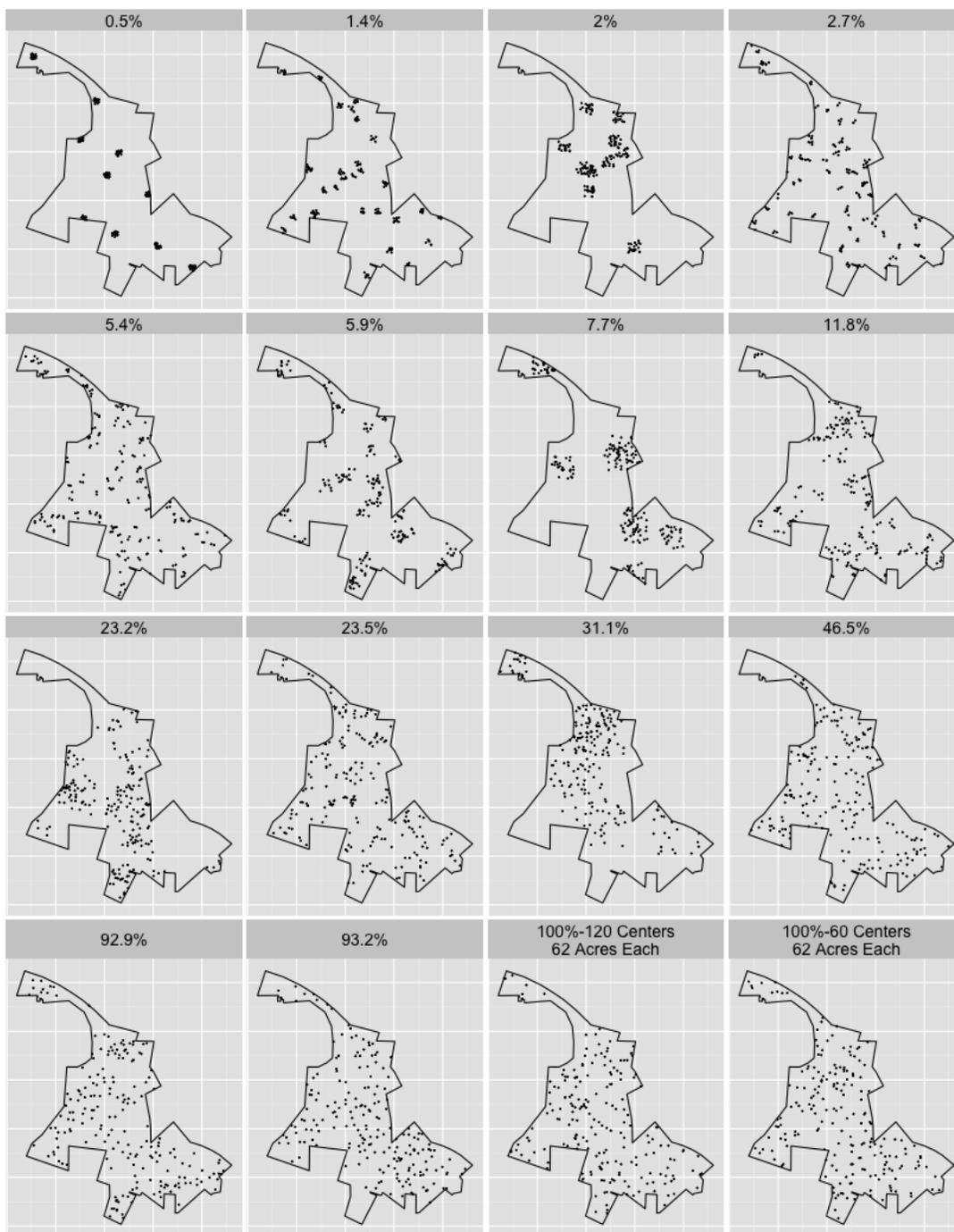
Figure 19. The 16 TOI Spatial Point Patterns Using a Rate of 0.1 TOI Per Acre Used to Evaluate the Confidence Performance for Different Sampling Unit Dimensions

Table 10. Summary of the Calculated Number of Acres Required for Each Confidence Design Case Used in this Simulation Study

Area Required Case	Confidence	TOI/acre	Number of acres calculated by confidence design
1	90	0.1	22.9
2	90	0.5	4.6
3	90	1.0	2.3
4	90	1.5	1.5
5	90	2.0	1.2
6	95	0.1	29.0
7	95	0.5	6.0
8	95	1.0	3.0
9	95	1.5	2.0
10	95	2.0	1.5
11	99	0.1	45.5
12	99	0.5	9.2
13	99	1.0	4.6
14	99	1.5	3.1
15	99	2.0	2.3
16	99.9	0.1	67.9
17	99.9	0.5	13.8
18	99.9	1.0	6.9
19	99.9	1.5	4.6
20	99.9	2.0	3.4

For each design type (transect dimension, confidence, and TOI rate) the achieved confidence is calculated by finding the percentage of the 2300 iterations (random transect selections) that had at least one TOI within a transect from that sample. The TOI rate upon which the design type was built is placed within the Motlow boundary area using one of the 17 TOI point patterns described previously (16 TOI clustering patterns and the one uniform TOI pattern). If a transect design (calculated survey area) is devised to detect a specified TOI rate with 90% confidence and the true TOI rate upon which the design is applied is equal to the design rate and uniformly distributed within the sample area, repeated sampling would result in 10% of the repeated transect samples not containing TOI. We show the results for random sampling in this report as the results from systematic and random had no observable differences in performance.

Figure 20 shows the achieved confidence results (y-axis) for the varied designs from the 2300 iterations as applied to the TOI point patterns shown in Figure 17. Each panel of Figure 20 shows the achieved results with the as-designed confidence listed at the top of the panel (y-axis scale varies in each panel). The horizontal solid black line is the approximately 3 standard deviation lower bound on the as-designed (horizontal dotted line) confidence. Most of the cases fall within the 3 standard deviation boundary as expected. As we have only run 2300 simulations for each design type, we would expect a few of the cases to fall outside the boundaries as shown in Figure 20. These results validate that the simulation is performing correctly and allow us to examine the robustness in confidence as the TOI point pattern deviates from a uniform distribution.
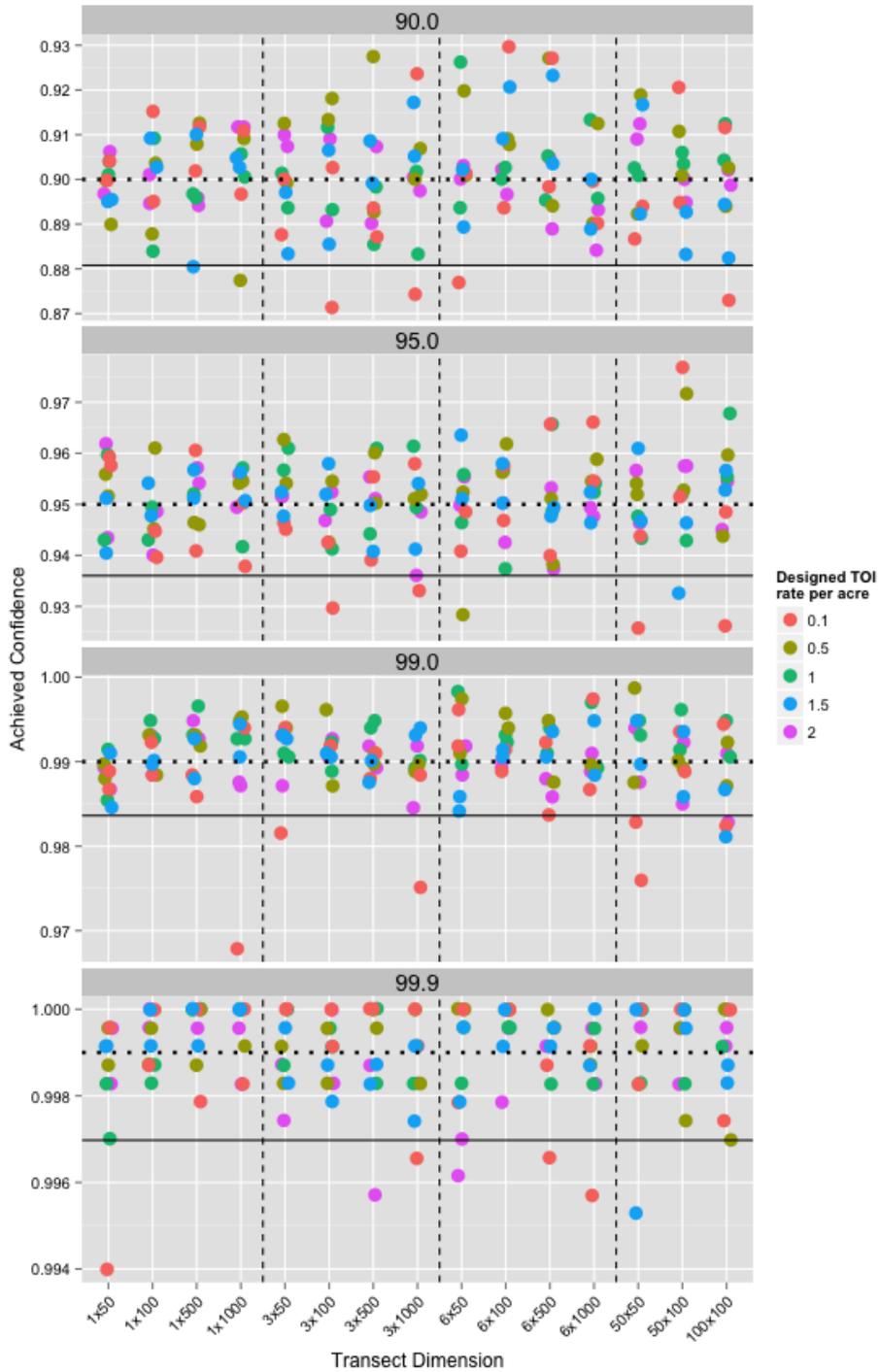
Figure 20. Achieved confidence (y-axis) for the varied confidence (panel), TOI rates (color of points) and sampling unit dimension (x-axis) for the uniformly distributed points as shown in Figure 20.

Figure 21, Figure 22, and Figure 23 provide the achieved confidence results for the varied sampling unit dimensions and type of clustering as categorized by the maximum percent of the area where TOI could be placed. We grouped results into TOI placement that is extremely clustered, has some clustering, and little to no clustering. These groupings were defined below:

- Extremely clustered – Less than 12% of the sample area having the potential to contain TOI
- Some clustering – Between 23% and 50% of the sample area having the potential to contain TOI
- Little to no clustering – Greater than 90% of the sample area having the potential to contain TOI.

For the extreme clustering cases (Figure 21), the results show that if the TOI rate is above 0.5/ acre, the desired confidence is not achieved except for perhaps the narrower, shorter transects. For the some clustering cases (Figure 22), all the 1 meter and 3 meter wide transects meet the designed confidence with exception of a few of the 2 TOI/acre designs (which would most likely be very unexpected on this type of site area). None of the grid survey options met the as-designed confidence and generally perform poorly when there is some clustering. Finally, for the little to no clustering cases (Figure 23), all transect sampling units meet the designed confidence. The grid-sized transects (50 x 50, 100 x 100, and 50 x 100 meter) did not perform well. The very low TOI rate design of 0.1 TOI/acre met confidence designs for the grids in some cases and all transect sampling unit cases.

Similar to the conclusions reported in the previous simulation studies on appropriate transect dimensions, transect sampling is always recommended over grid sampling to attain a representative sample that is robust to clustered TOI point patterns. The shorter and narrower transects are more robust to strong clustering in TOI locations. The typically used 1 meter and 3 meter wide transects perform well in most cases and can be expected to perform well for TOI rates below 0.5/acre even with extreme clustering of TOI.
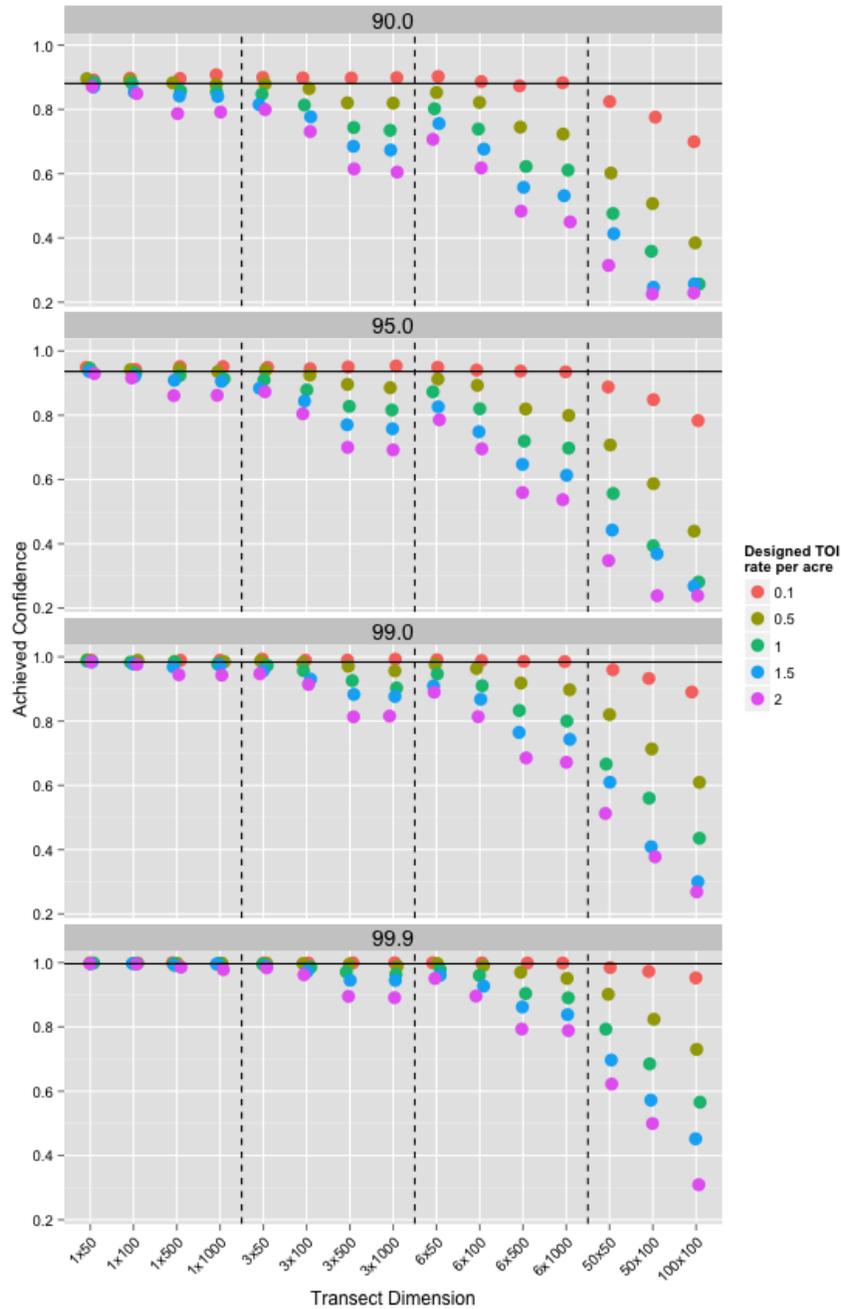
Figure 21. Achieved confidence (y-axis) for the varied confidence (panel), TOI rates (color of points) and sampling unit dimension (x-axis) for the TOI point patterns that restrain points to fall in no more than 12% of the sample area. The solid horizontal line is the 3 standard deviation lower bound of confidence performance from a simulation study using 2300 simulations to evaluate confidence. The vertical dashed lines separate the three transect widths and the grid based sampling units.
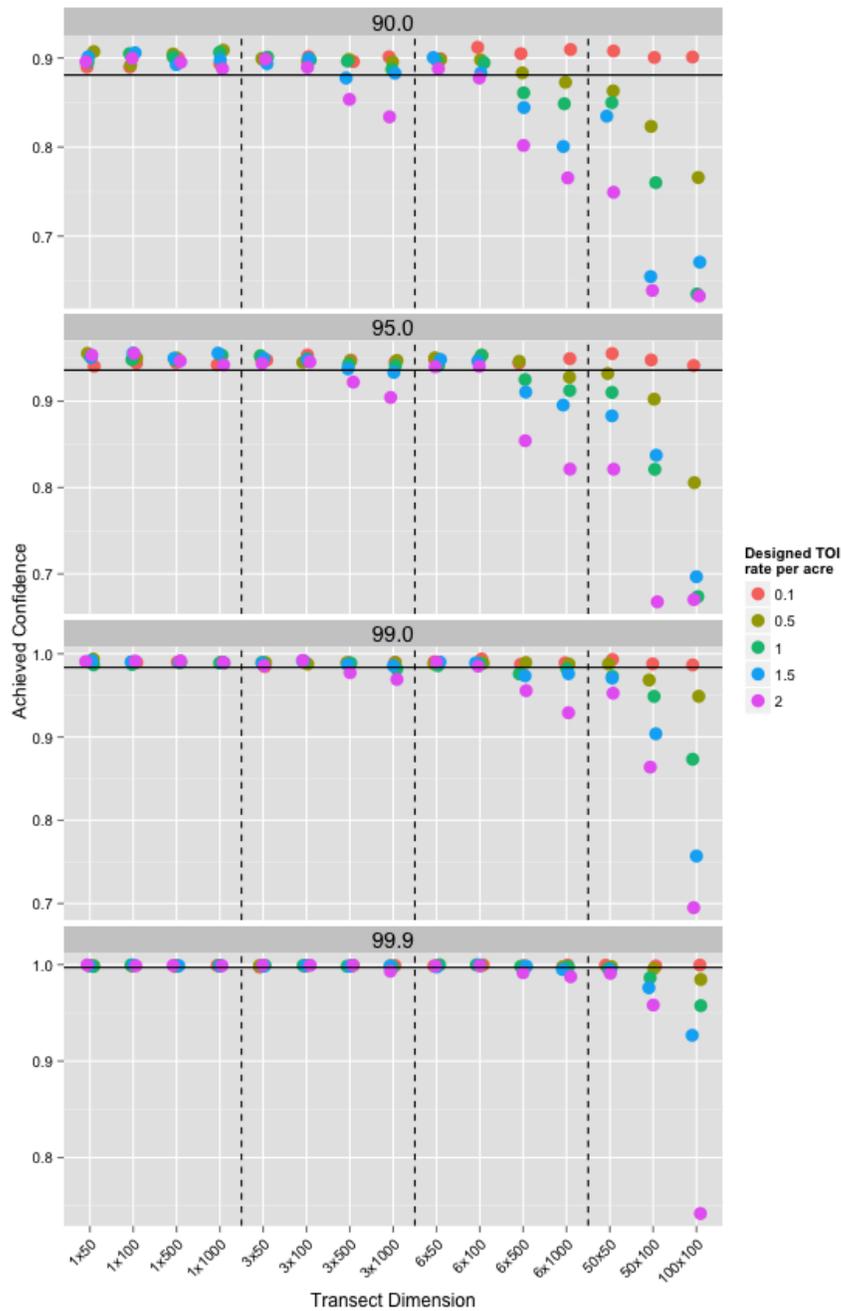
Figure 22. Achieved confidence (y-axis) for the varied confidence (panel), TOI rates (color of points) and sampling unit dimension (x-axis) for the TOI point patterns that restrain points to fall in no more than 50% but greater than 23% of the sample area. The solid horizontal line is the 3 standard deviation lower bound of confidence performance from a simulation study using 2300 simulations to evaluate confidence. The vertical lines separate the three transect widths and the grid based sampling units.
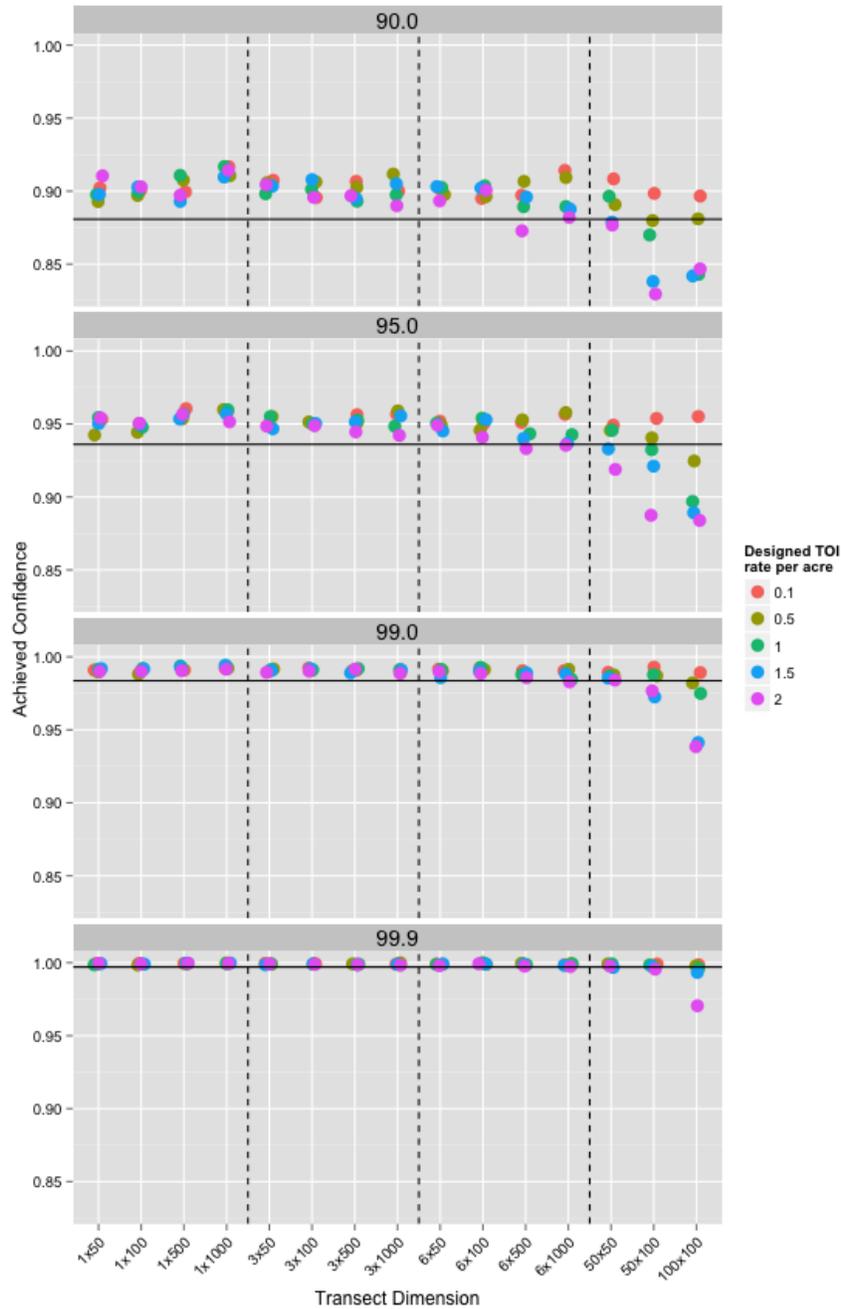
Figure 23. Achieved confidence (y-axis) for the varied confidence (panel), TOI rates (color of points) and sampling unit dimension (x-axis) for the TOI point patterns that restrain points to fall in greater than 90% of the sample area. The solid horizontal line is the 3 standard deviation lower bound of confidence performance from a simulation study using 2300 simulations to evaluate confidence. The vertical lines separate the three transect widths and the grid based sampling units.

7.6 Objective 6 Assessment: Compare the Utility of Different Possible Target Area Boundary Delineation Methods

Because of the complexity of these methods, they were not fully developed in time for this demonstration. They are nearing completion and will be included in a future VSP release and tested/demonstrated on a site in the future.

8 COST ASSESSMENT

PNNL's VSP software is freely available at no cost to the user. Costs for conducting transect surveys are borne by the geophysical survey contractors. VSP can help minimize these costs by helping develop an optimal transect survey design. The following table (Table 11) does identify some potential costs that are primarily in the form of man hours. However, the benefit of having an acceptable data quality objective-based design can potentially reduce the overall man hours cost of the remediation process. Obtaining sufficiently precise estimates of anomaly density, target area spatial extent, or TOI/acre will be important in accurately costing out any potential remediation.

Table 11. Potential Costs of Using VSP-RI Modules

Cost Element	Data
Use of VSP	Obtaining the software and learning how to use it • VSP Training hours • VSP Training costs • VSP Software – no cost
Transect Designs	Using VSP to develop the implemented surveyed transects for each type of area. • Could change originally planned survey costs required for VSP design
Geophysical Survey Costs	Cost per linear foot for conducting geophysical surveys can be factored in to the overall costs and any cost comparisons. Provided by survey contractor.
Interpretation/Analysis of Geophysical Survey Data	Average cost per identified anomaly of evaluating the geophysical surveys can be factored into the overall costs and any cost comparisons. Provided by survey contractor.
Digging and Anomaly Identification Costs	Cost of digging and identifying each anomaly can be factored into overall costs and any cost comparisons. Provided by contractor.

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Appendix A: Points of Contact

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone	Role in Project
Brent Pulsipher	PNNL	(509) 375-3989	Principal Investigator
John Hathaway	PNNL	(509) 372-4970	Demonstration Lead
John Wilson	PNNL	(970) 270-2998	VSP Lead Programmer
Chris Cochrane	USACE	(256) 895-1696	USACE Project Lead
Elise Goggin	USACE	(256) 895-1635	USACE Project Geophysicist
Karl Blankinship	USACE, Mobile Office	(256) 682-7546	USACE District Project Manager
John Hoffelt	Tennessee Department of Environmental and Conservation (TDEC)	(615) 687-7067	Regulator
Christian tenBraak	Parsons	(303) 764-1923	Contractor Project Manager
Carrie Ross	Parsons	(303) 764-8736	Contractor Deputy Project Manager
Craig Murray	Parsons	(303) 764-8868	Contractor Geophysicist

Appendix B: Area 3a Dig Results

Project	Location	Unique Target ID	Easting (UTM meters)	Northing (UTM meters)	Fiducial (Yes or No)	CH2 (mV)	Date	Pre_ mV	Post_ mV	Anomaly Type	# of contacts	Depth (cm)	Description	Item_length (cm)	Grid	Photo ID	Agreement between Dig Results & GEO Data (G=good, P=poor, U = unacceptable)	GEO QC Initials	Comments
PNNL	Site 3a	Site 3aTransect 10A-001	567496.0	3911336.8	Yes	7.79	7/10/2013	8	0	OD	1	2	Scrap	11	Site 3aTransect10A	Site3AGridT10A_ 0001	G	SS	
PNNL	Site 3a	Site 3aTransect 10A-002	567489.0	3911420.3	Yes	13.97	7/10/2013	40	0	OD	1	0	Scrap Chain	50	Site 3aTransect10A	Site3AGridT10A_ 0002	G	SS	
PNNL	Site 3a	Site 3aTransect 10A-003	567548.7	3911497.2	Yes	6.08	7/10/2013	11	0	OD	1	5	Scrap	10	Site 3aTransect10A	Site3AGridT10A_ 0003	G	SS	
PNNL	Site 3a	Site 3aTransect 10A-004	567552.5	3911637.8	Yes	74.25	7/10/2013	75	0	OD	1	5	Scrap	20	Site 3aTransect10A	Site3AGridT10A_ 0004	G	SS	
PNNL	Site 3a	Site 3aTransect 10A-005	567552.5	3911721.1	Yes	6.03	7/10/2013	6	0	OD	1	5	Scrap Wire	4	Site 3aTransect10A	Site3AGridT10A_ 0005	G	SS	
PNNL	Site 3a	Site 3aTransect 10A-006	567540.5	3911752.3	Yes	9.96	7/10/2013	36	0	OD	1	3	Scrap	10	Site 3aTransect10A	Site3AGridT10A_ 0006	G	SS	
PNNL	Site 3a	Site 3aTransect 10A-007	567525.6	3911781.0	Yes	171.23	7/10/2013	180	30	OD	1	20	Scrap	40	Site 3aTransect10A	Site3AGridT10A_ 0007	G	SS	
PNNL	Site 3a	Site 3aTransect 10A-008	567519.2	3911804.9	Yes	6.67	7/10/2013	8	4	OD	1	15	Rust in dirt	1	Site 3aTransect10A	Site3AGridT10A_ 0008	G	SS	

PNNL	Site 3a	Site 3aTransect 10A-009	567516.3	3911831.5	Yes	4.97	7/10/2013	0	0	NC	0		No Find		Site 3aTransect10A	Site3AGridT10A_0009	G	SS
PNNL	Site 3a	Site 3aTransect 10A-010	567516.6	3911851.6	Yes	7.94	7/10/2013	3	0	NC	0		No Find		Site 3aTransect10A	Site3AGridT10A_0010	G	SS
PNNL	Site 3a	Site 3aTransect 10A-011	567516.6	3911856.8	Yes	6414.62	7/10/2013	6400	6400	OD	1	61	Culvert	914	Site 3aTransect10A	Site3AGridT10A_0011	G	SS
PNNL	Site 3a	Site 3aTransect 10A-012	567516.6	3911864.3	Yes	11.84	7/10/2013	20	0	OD	1	10	Scrap	17	Site 3aTransect10A	Site3AGridT10A_0012	G	SS
PNNL	Site 3a	Site 3aTransect 10A-013	567564.0	3911900.6	Yes	6.32	7/10/2013	8	0	OD	1	2	Scrap	11	Site 3aTransect10A	Site3AGridT10A_0013	G	SS
PNNL	Site 3a	Site 3aTransect 10A-014	567566.6	3911911.3	Yes	41.06	7/10/2013	44	0	OD	1	15	Scrap	10	Site 3aTransect10A	Site3AGridT10A_0014	G	SS
PNNL	Site 3a	Site 3aTransect 10A-015	567566.6	3911929.1	Yes	22.73	7/10/2013	17	0	OD	1	4	Horse shoe	15	Site 3aTransect10A	Site3AGridT10A_0015	G	SS
PNNL	Site 3a	Site 3aTransect 10A-016	567592.1	3911967.9	Yes	7.68	7/10/2013	14	0	OD	1	5	Horse shoe	12	Site 3aTransect10A	Site3AGridT10A_0016	G	SS
PNNL	Site 3a	Site 3aTransect 10A-017	567592.1	3911973.4	Yes	8.34	7/10/2013	6	0	OD	1	5	Scrap	10	Site 3aTransect10A	Site3AGridT10A_0017	G	SS
PNNL	Site 3a	Site 3aTransect 10A-018	567592.1	3911977.2	Yes	14.52	7/10/2013	20	0	OD	1	7	Horse shoe	12	Site 3aTransect10A	Site3AGridT10A_0018	G	SS
PNNL	Site 3a	Site 3aTransect 10A-019	567581.4	3911990.4	Yes	6.12	7/10/2013	12	0	OD	1	4	Scrap	2	Site 3aTransect10A	Site3AGridT10A_0019	G	SS
PNNL	Site 3a	Site 3aTransect 10A-020	567505.8	3912015.7	Yes	35.87	7/10/2013	42	0	OD	1	15	Horse shoe	15	Site 3aTransect10A	Site3AGridT10A_0020	G	SS

PNNL	Site 3a	Site 3aTransect 10A-021	567505.8	3912016.3	Yes	49.52	7/10/2013	42	0	OD	1	15	Horse shoe	15	Site 3aTransect10A	Site3AGridT10A_0021	G	SS
PNNL	Site 3a	Site 3aTransect 10A-022	567511.1	3912218.4	Yes	6.35	7/10/2013	8	0	OD	1	5	Scrap	35	Site 3aTransect10A	Site3AGridT10A_0022	G	SS
PNNL	Site 3a	Site 3aTransect 10A-023	567524.0	3912231.4	Yes	64.59	7/10/2013	100	0	OD	1	18	Scrap	35	Site 3aTransect10A	Site3AGridT10A_0023	G	SS
PNNL	Site 3a	Site 3aTransect 12A-001	568359.3	3911729.2	Yes	91.63	7/10/2013	1300	0	OD	1	1	Sheet Metal	20	Site 3aTransect12A	Site3aGridT12A_001	G	SS
PNNL	Site 3a	Site 3aTransect 12A-003	568346.2	3911755.7	Yes	8.29	7/10/2013	8	0	OD	1	5	Nail	10	Site 3aTransect12A	Site3aGridT12A_003	G	SS
PNNL	Site 3a	Site 3aTransect 12A-004	568339.5	3911789.0	Yes	14.76	7/10/2013	7	5	OD	1	6	Nail Pit	5	Site 3aTransect12A	Site3aGridT12A_004	G	SS
PNNL	Site 3a	Site 3aTransect 12A-005	568322.4	3911808.3	Yes	9.31	7/10/2013	12	2	OD	1	5	Nail	10	Site 3aTransect12A	Site3aGridT12A_005	G	SS
PNNL	Site 3a	Site 3aTransect 12A-006	568322.4	3911815.2	Yes	23.43	7/10/2013	33	9	OD	1	5	Nail Pit	10	Site 3aTransect12A	Site3aGridT12A_006	G	SS
PNNL	Site 3a	Site 3aTransect 12A-007	568294.3	3911841.2	Yes	6.54	7/10/2013	12	0	OD	1	3	Nail	13	Site 3aTransect12A	Site3aGridT12A_007	G	SS
PNNL	Site 3a	Site 3aTransect 12A-008	568294.3	3911843.5	Yes	13.53	7/10/2013	15	0	OD	1	5	Nail Pit	10	Site 3aTransect12A	Site3aGridT12A_008	G	SS
PNNL	Site 3a	Site 3aTransect 12A-010	568264.6	3911944.5	Yes	41.55	7/10/2013	40	0	OD	1	5	Scrap Metal	25	Site 3aTransect12A	Site3aGridT12A_010	G	SS

PNNL	Site 3a	Site 3aTransect 2A-001	564642.2	3915667.0	Yes	7.13	7/15/2013	3		OD	1	4	Scrap	3	Site 3aTransect2A	Site3AGridT2A_0001.JPG	G	SS	Pre Mv unattainable due to high voltage lines
PNNL	Site 3a	Site 3aTransect 2A-002	564642.2	3915668.0	Yes	5.68	7/15/2013	N/A	N/A	NC	0		No Find		Site 3aTransect2A	Site3AGridT2A_0002.JPG	G	SS	Pre Mv unattainable due to high voltage lines
PNNL	Site 3a	Site 3aTransect 2A-003	564628.7	3915792.0	Yes	9.01	7/15/2013	N/A	N/A	NC	0		No Find		Site 3aTransect2A	Site3AGridT2A_0003.JPG	G	SS	Pre Mv unattainable due to high voltage lines
PNNL	Site 3a	Site 3aTransect 2A-004	564628.7	3915798.1	Yes	7.21	7/15/2013	N/A	N/A	NC	0		No Find		Site 3aTransect2A	Site3AGridT2A_0004.JPG	G	SS	Pre Mv unattainable due to high voltage lines
PNNL	Site 3a	Site 3aTransect 2A-005	564619.7	3915796.9	Yes	7.88	7/15/2013	N/A	N/A	NC	0		No Find		Site 3aTransect2A	Site3AGridT2A_0005.JPG	G	SS	Pre Mv unattainable due to high voltage lines
PNNL	Site 3a	Site 3aTransect 2A-006	564620.0	3915832.2	Yes	7.08	7/15/2013	N/A	N/A	NC	0		No Find		Site 3aTransect2A	Site3AGridT2A_0006.JPG	G	SS	Pre Mv unattainable due to high voltage lines

PNNL	Site 3a	Site 3aTransect 2A-007	564613.6	3915863.3	Yes	5.83	7/15/2013	N/A	N/A	NC	0		No Find		Site 3aTransect2A	Site3AGridT2A_0007.JPG	G	SS	Pre Mv unattainable due to high voltage lines
PNNL	Site 3a	Site 3aTransect 2A-008	564613.6	3915864.5	Yes	7.98	7/15/2013	N/A	N/A	NC	0		No Find		Site 3aTransect2A	Site3AGridT2A_0008.JPG	G	SS	Pre Mv unattainable due to high voltage lines
PNNL	Site 3a	Site 3aTransect 2A-009	564613.6	3915880.3	Yes	8.89	7/15/2013	N/A	N/A	NC	0		No Find		Site 3aTransect2A	Site3AGridT2A_0009.JPG	G	SS	Pre Mv unattainable due to high voltage lines
PNNL	Site 3a	Site 3aTransect 2A-010	564613.6	3915884.7	Yes	9.5	7/15/2013	N/A	N/A	NC	0		No Find		Site 3aTransect2A	Site3AGridT2A_0010.JPG	G	SS	Pre Mv unattainable due to high voltage lines
PNNL	Site 3a	Site 3aTransect 2A-012	564644.2	3916000.6	Yes	4.22	7/15/2013	20	0	OD	1	0	Scrap		Site 3aTransect2A	Site3AGridT2A_0012.JPG	G	SS	
PNNL	Site 3a	Site 3aTransect 2C-001	564603.3	3912920.1	Yes	10.46	7/15/2013	12	0	Munitions Debris	1	4	Frag	12	Site 3aTransect2C	Site3AGridT2C_0001.JPG	G	SS	
PNNL	Site 3a	Site 3aTransect 6B-002	566091.2	3913630.3	Yes	6.53	7/11/2013	6	0	OD	1	5	Scrap	10	Site 3aTransect t6B	Site3AGridT6B_0002.JPG	G	SS	
PNNL	Site 3a	Site 3aTransect 6B-003	566096.7	3913699.5	Yes	6.12	7/11/2013	30	0	OD	1	7	Horseshoe	15	Site 3aTransect t6B	Site3AGridT6B_0003.JPG	G	SS	

PNNL	Site 3a	Site 3aTransect 6B-004	566088.4	3913851.2	Yes	15.81	7/11/2013	20	0	OD	1	2	Barbwire	40	Site 3aTransect6B	Site3AGridT6B_0004.JPG	G	SS
PNNL	Site 3a	Site 3aTransect 6C-001	566139.1	3911166.1	Yes	8.64	7/11/2013	10	5	OD	1	5	Nail Pit	12	Site 3aTransect6C	Site3AGridT6C_0001.JPG	G	SS
PNNL	Site 3a	Site 3aTransect 6C-003	566144.4	3911270.4	Yes	35.66	7/11/2013	30	0	OD	1	6	Wire	40	Site 3aTransect6C	Site3AGridT6C_0003.JPG	G	SS
PNNL	Site 3a	Site 3aTransect 6C-004	566125.6	3911271.0	Yes	107.83	7/11/2013	100	0	OD	1	10	Horseshoe	15	Site 3aTransect6C	Site3AGridT6C_0004.JPG	G	SS
PNNL	Site 3a	Site 3aTransect 6C-006	566134.5	3911592.1	Yes	6.45	7/15/2013	10	0	OD	1	3	Nails	12	Site 3aTransect6C	Site3AGridT6C_0006.JPG	G	SS
PNNL	Site 3a	Site 3aTransect 6C-007	566131.1	3912610.4	Yes	38.36	7/15/2013	40	0	OD	1	7	Horseshoe	21	Site 3aTransect6C	Site3AGridT6C_0007.JPG	G	SS
PNNL	Site 3a	Site 3aTransect 6C-008	566106.4	3912741.7	Yes	6.89	7/15/2013	18	0	OD	1	4	Horseshoe	10	Site 3aTransect6C	Site3AGridT6C_0008.JPG	G	SS
PNNL	Site 3a	Site 3aTransect 8B-001	566837.8	3913678.9	Yes	10.94	7/15/2013	11	0	OD	1	0	Nails	8	Site 3aTransect8B	Site3AGridT8B_0001.JPG	G	SS
PNNL	Site 3a	Site 3aTransect 8C-001	566841.5	3912251.0	Yes	35.35	7/15/2013	40	0	OD	1	0	Barbwire	5	Site 3aTransect8C	Site3AGridT8C_0001.JPG	G	SS

Appendix C: Additional Cluster Pattern Plots and Achieved Confidence for Many of the Simulation Variations
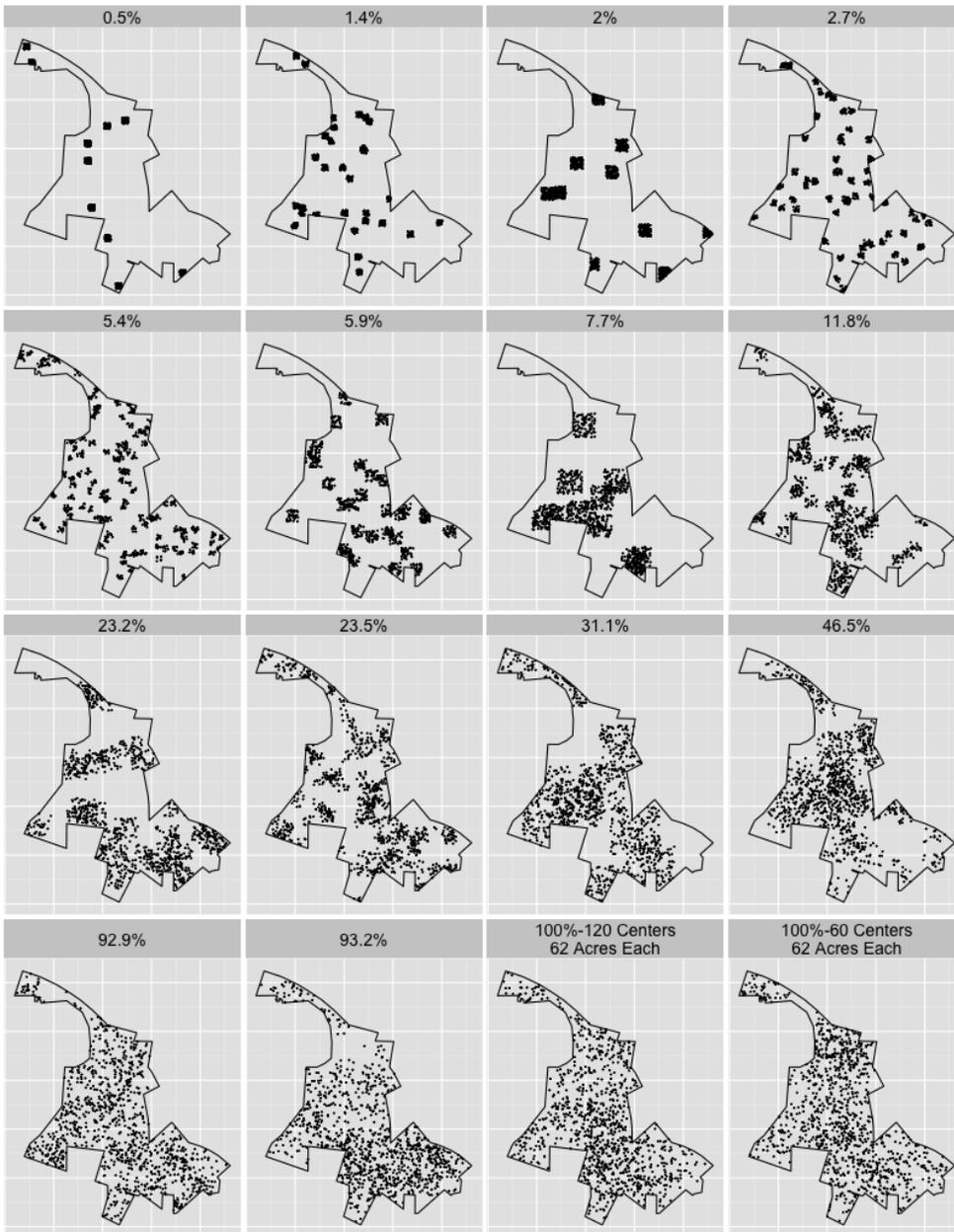

Figure C-1. The 16 TOI spatial point patterns using a rate of 0.5 TOI per acre used to evaluate the confidence performance for different sampling unit dimensions.
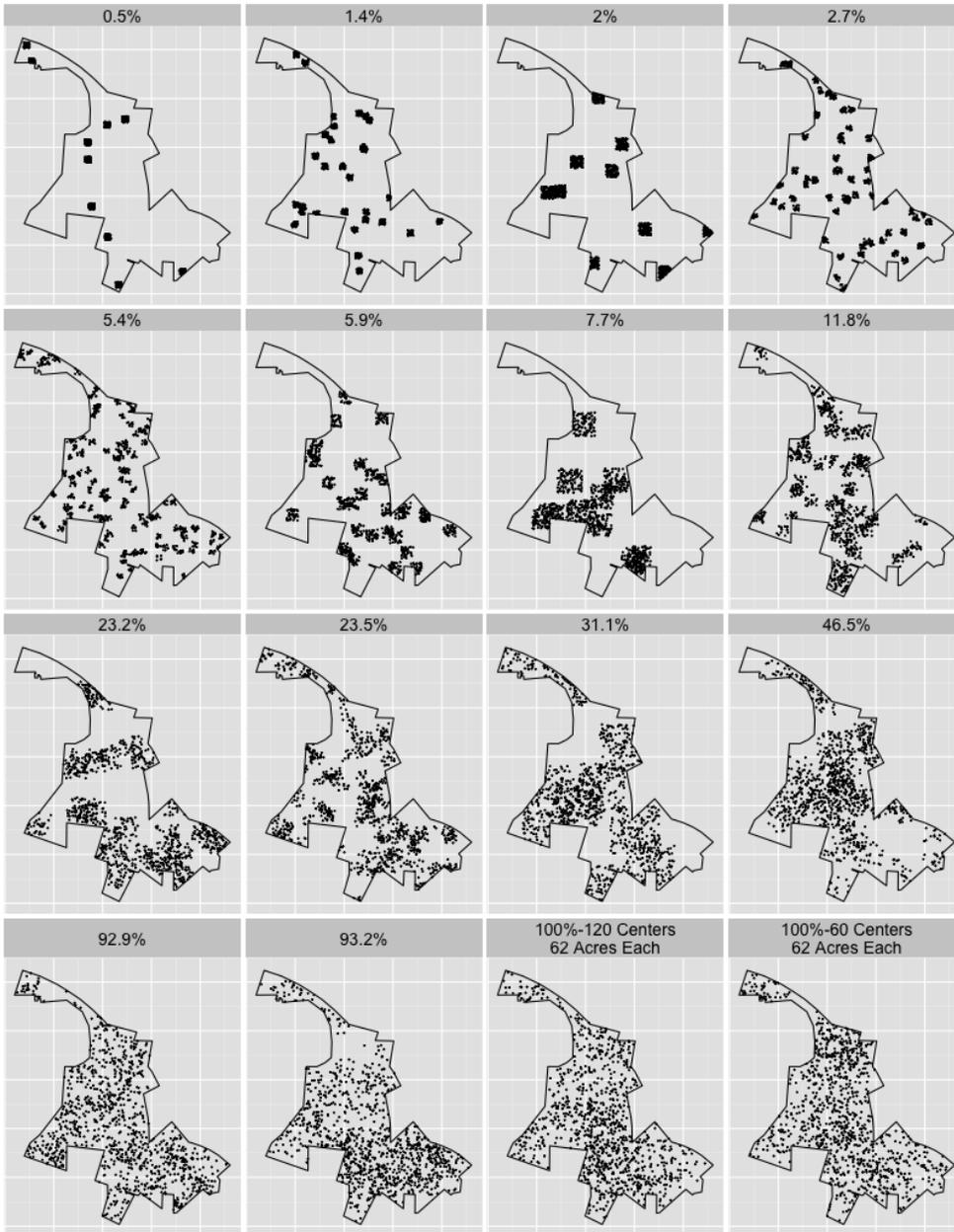
Figure C-2. The 16 TOI spatial point patterns using a rate of 1.5 TOI per acre used to evaluate the confidence performance for different sampling unit dimensions.
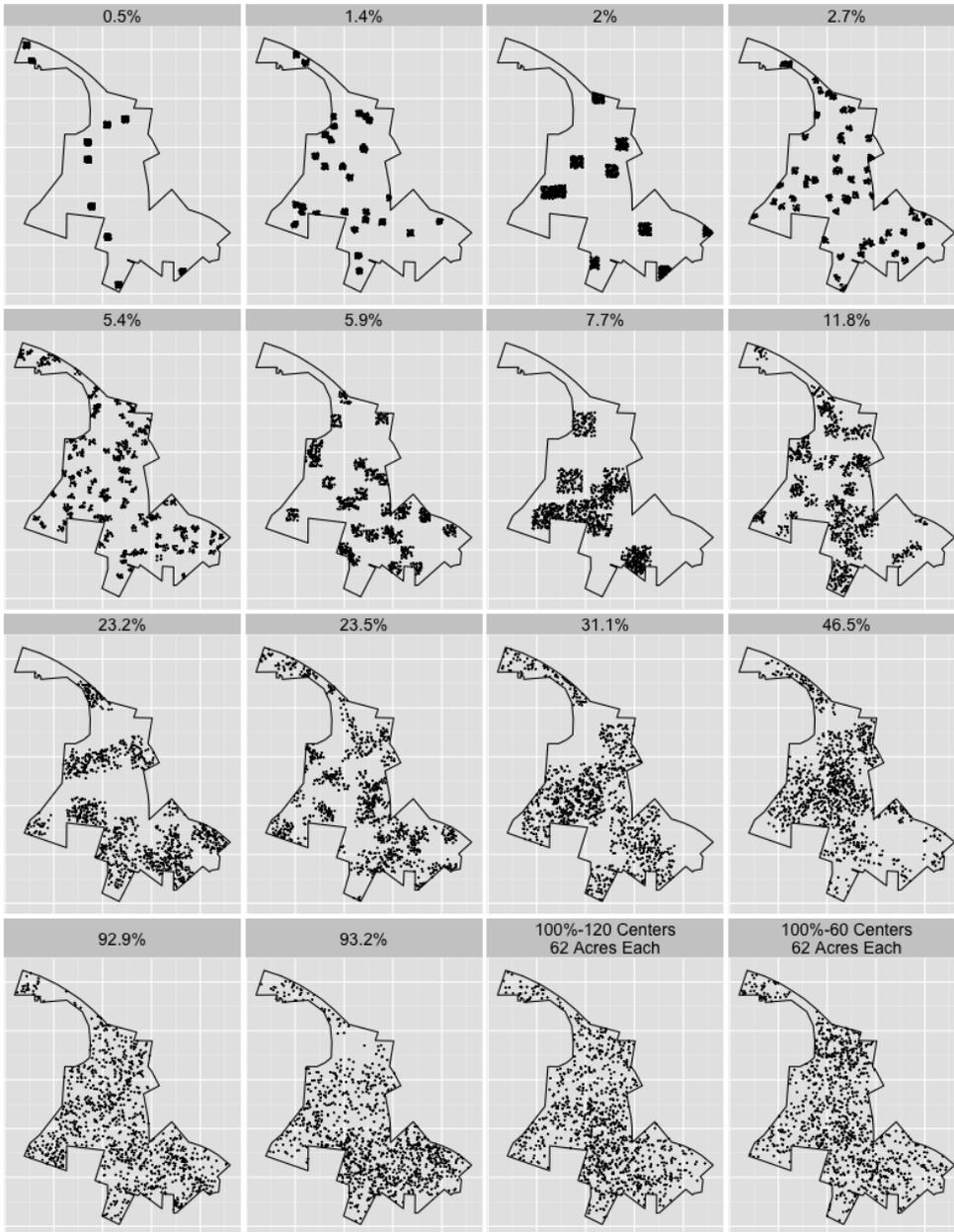
Figure C-3. The 16 TOI spatial point patterns using a rate of 2 TOI per acre used to evaluate the confidence performance for different sampling unit dimensions.

10 random cluster centers with a maximum of 1.9% of the area available for TOI placement
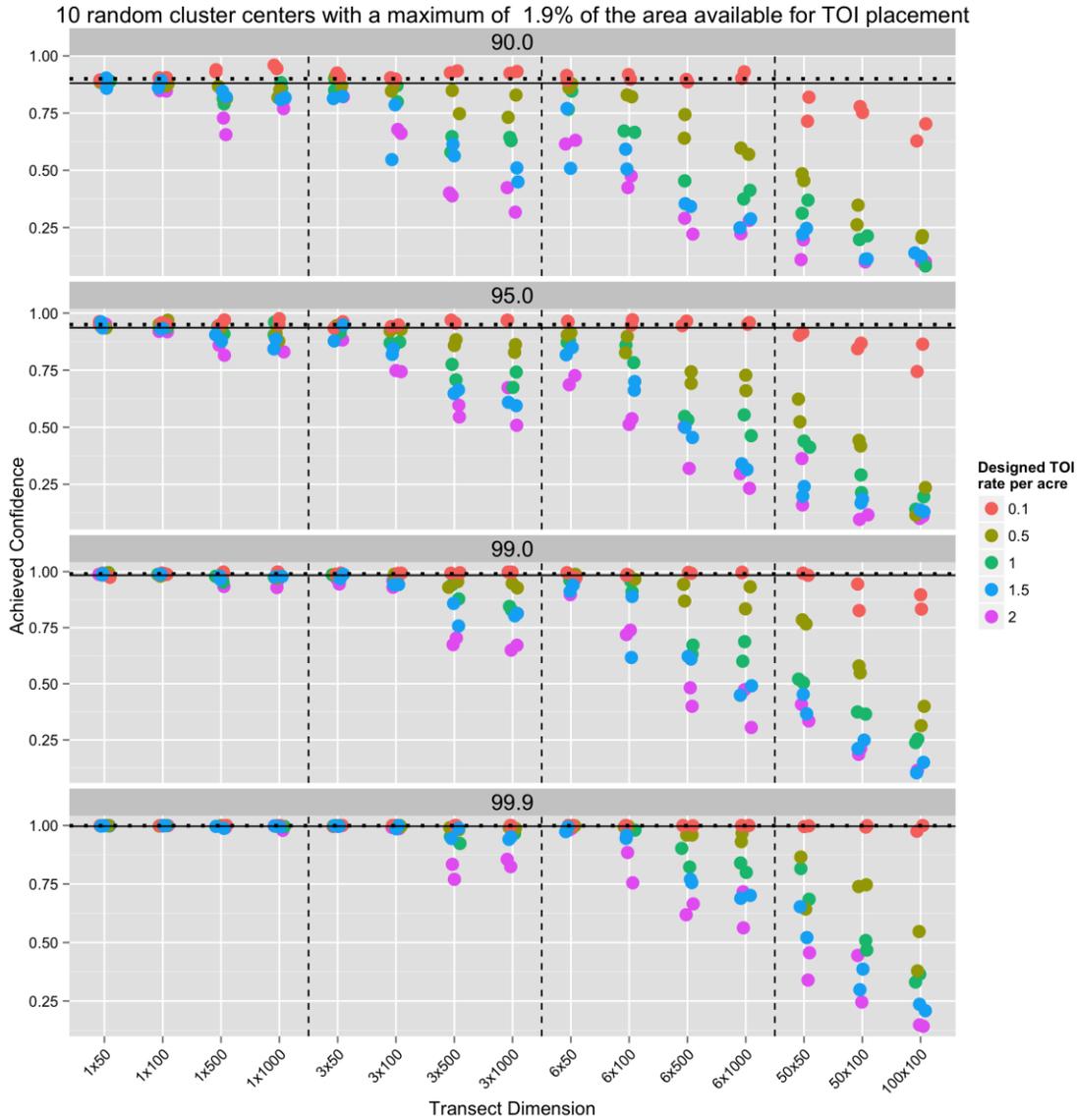
Figure C-4. Achieved confidence performance (y-axis) plots for 10 random cluster centers with all points within a square area of 3.9 acres around each grid center, which results in a maximum of 1.9% of the Motlow boundary area of 1989 acres having potential for TOI placement. The sampling unit dimensions are shown on the x-axis. The horizontal dotted line marks the designed confidenceand the solid horizontal line is the 3 standard deviation lower bound for confidence performance of a simulation study using 2300 simulations to evaluate confidence. The vertical lines separate the three transect widths and the grid based sampling units.
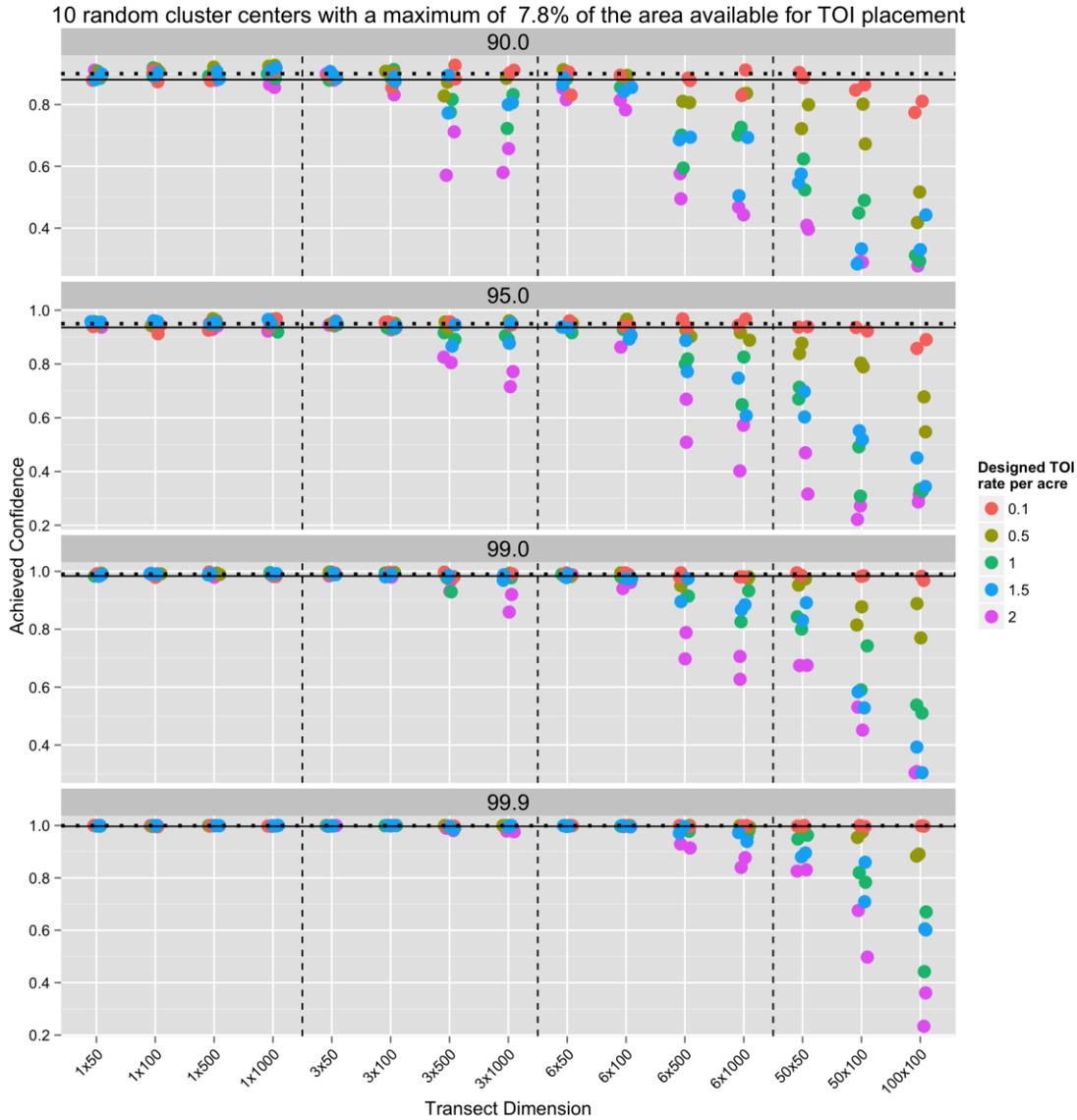
Figure C-5. Achieved confidence performance (y-axis) plots for 10 random cluster centers with all points within a square area of 15.4 acres around each grid center, which results in a maximum of 7.8% of the Motlow boundary area of 1989 acres having potential for TOI placement. The sampling unit dimensions are shown on the x-axis. The horizontal dotted line marks the designed confidence and the solid horizontal line is the 3 standard deviation lower bound for confidence performance of a simulation study using 2300 simulations to evaluate confidence. The vertical lines separate the three transect widths and the grid based sampling units.

10 random cluster centers with a maximum of 31.1% of the area available for TOI placement
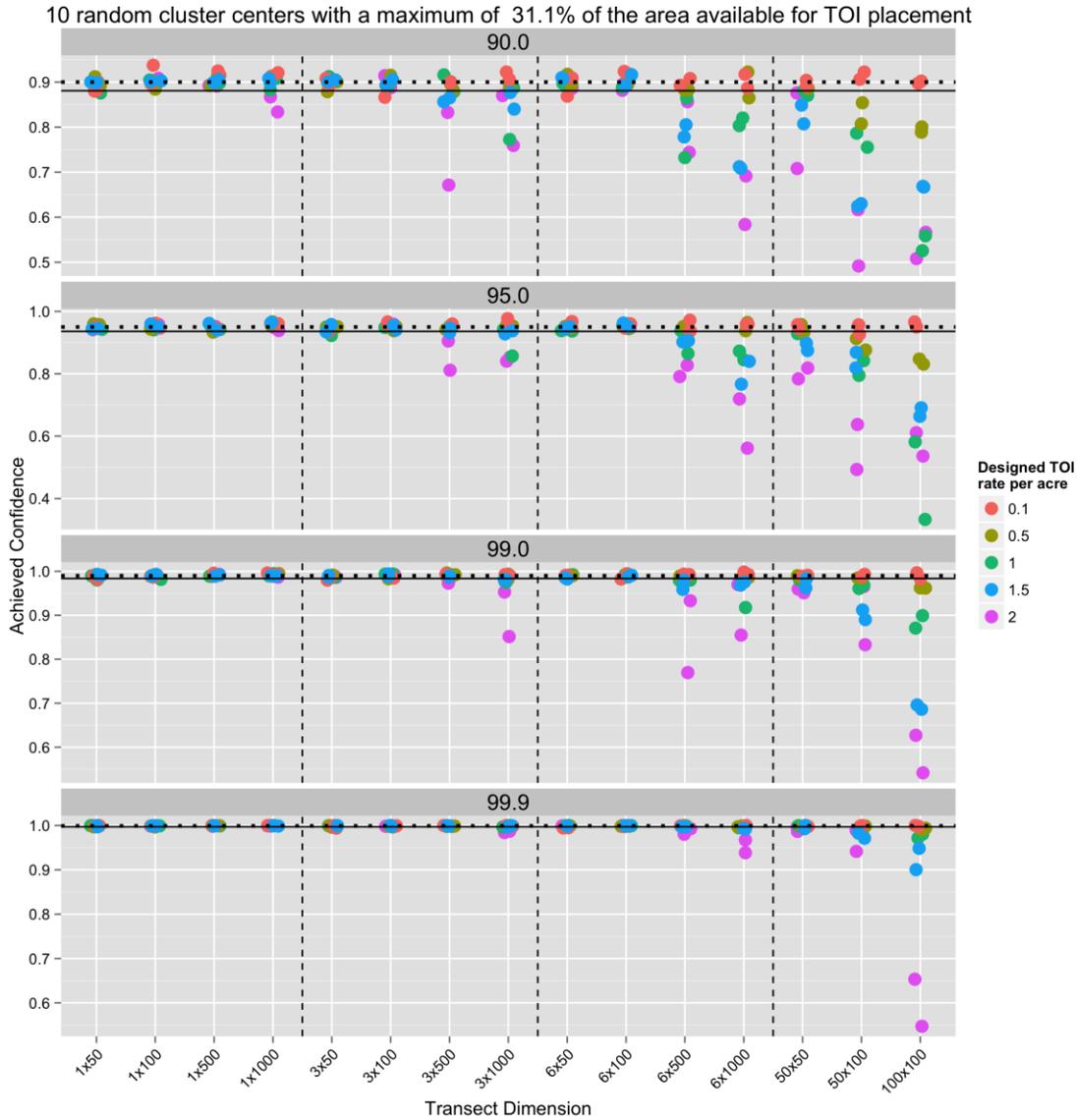
Figure C-6. Achieved confidence performance (y-axis) plots for 10 random cluster centers with all points within a square area of 61.8 acres around each grid center, which results in a maximum of 31.1% of the Motlow boundary area of 1989 acres having potential for TOI placement. The sampling unit dimensions are shown on the x-axis. The horizontal dotted line marks the designed confidence and the solid horizontal line is the 3 standard deviation lower bound for confidence performance of a simulation study using 2300 simulations to evaluate confidence. The vertical lines separate the three transect widths and the grid based sampling units.

10 random cluster centers with a maximum of 0.4% of the area available for TOI placement
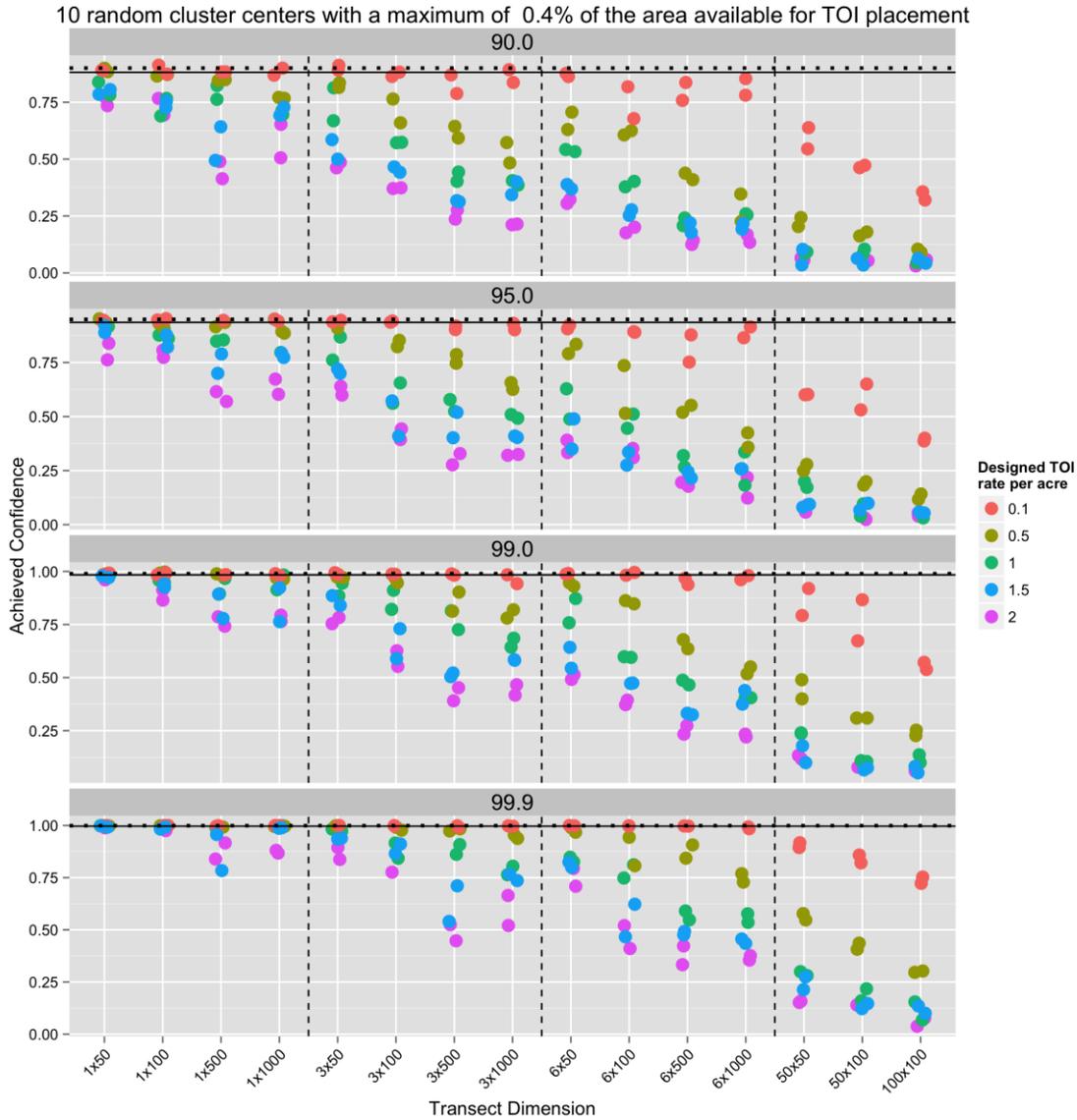
Figure C-7. Achieved confidence performance (y-axis) plots for 10 random cluster centers with all points within a square area of 0.9 acres around each grid center, which results in a maximum of 0.4% of the Motlow boundary area of 1989 acres having potential for TOI placement. The sampling unit dimensions are shown on the x-axis. The horizontal dotted line marks the designed confidenceand the solid horizontal line is the 3 standard deviation lower bound for confidence performance of a simulation study using 2300 simulations to evaluate confidence. The vertical lines separate the three transect widths and the grid based sampling units.

120 random cluster centers with a maximum of 23.3% of the area available for TOI placement
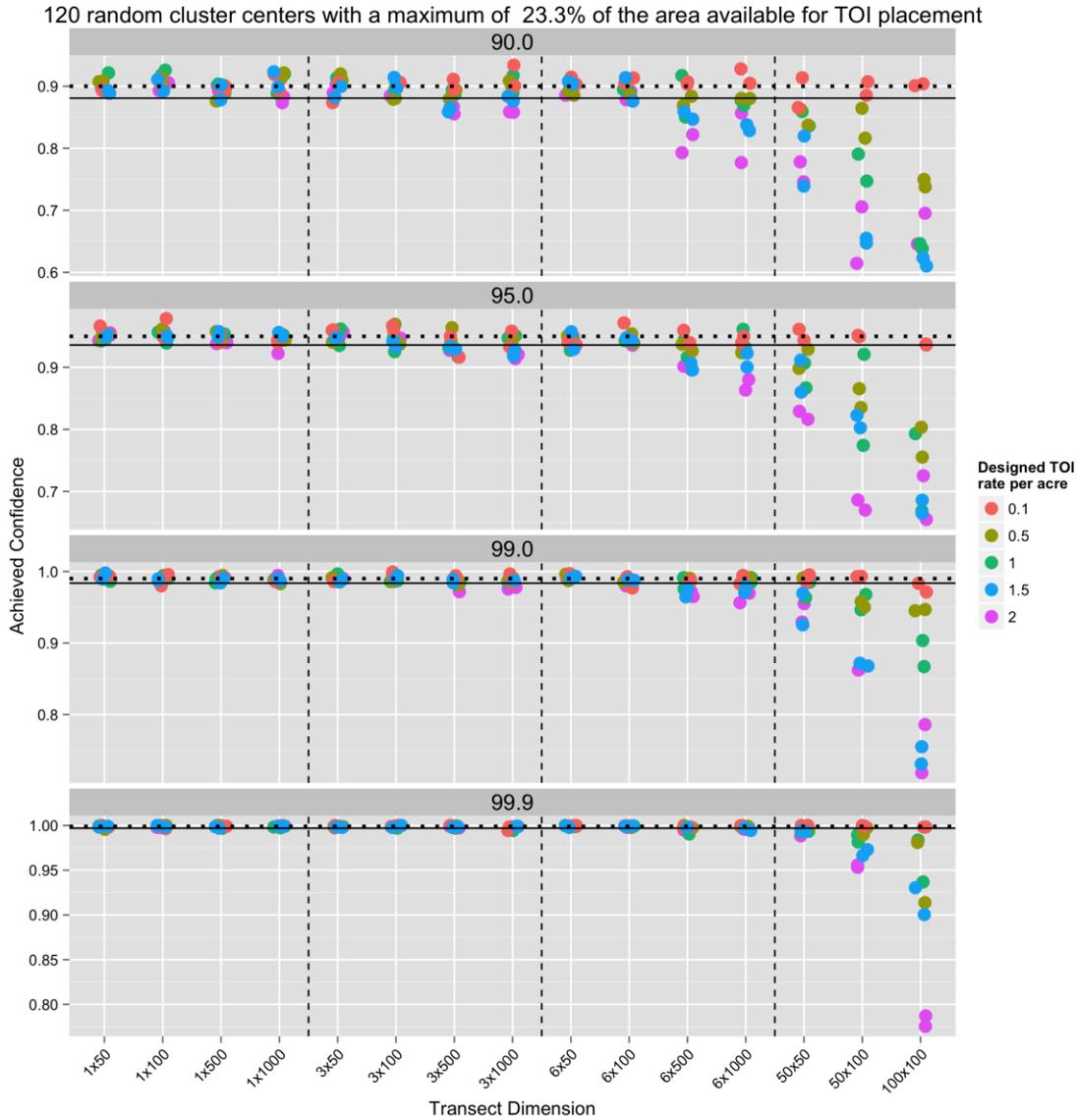
Figure C-8. Achieved confidence performance (y-axis) plots for 120 random cluster centers with all points within a square area of 3.9 acres around each grid center, which results in a maximum of 23.3% of the Motlow boundary area of 1989 acres having potential for TOI placement. The sampling unit dimensions are shown on the x-axis. The horizontal dotted line marks the designed confidenceand the solid horizontal line is the 3 standard deviation lower bound for confidence performance of a simulation study using 2300 simulations to evaluate confidence. The vertical lines separate the three transect widths and the grid based sampling units.
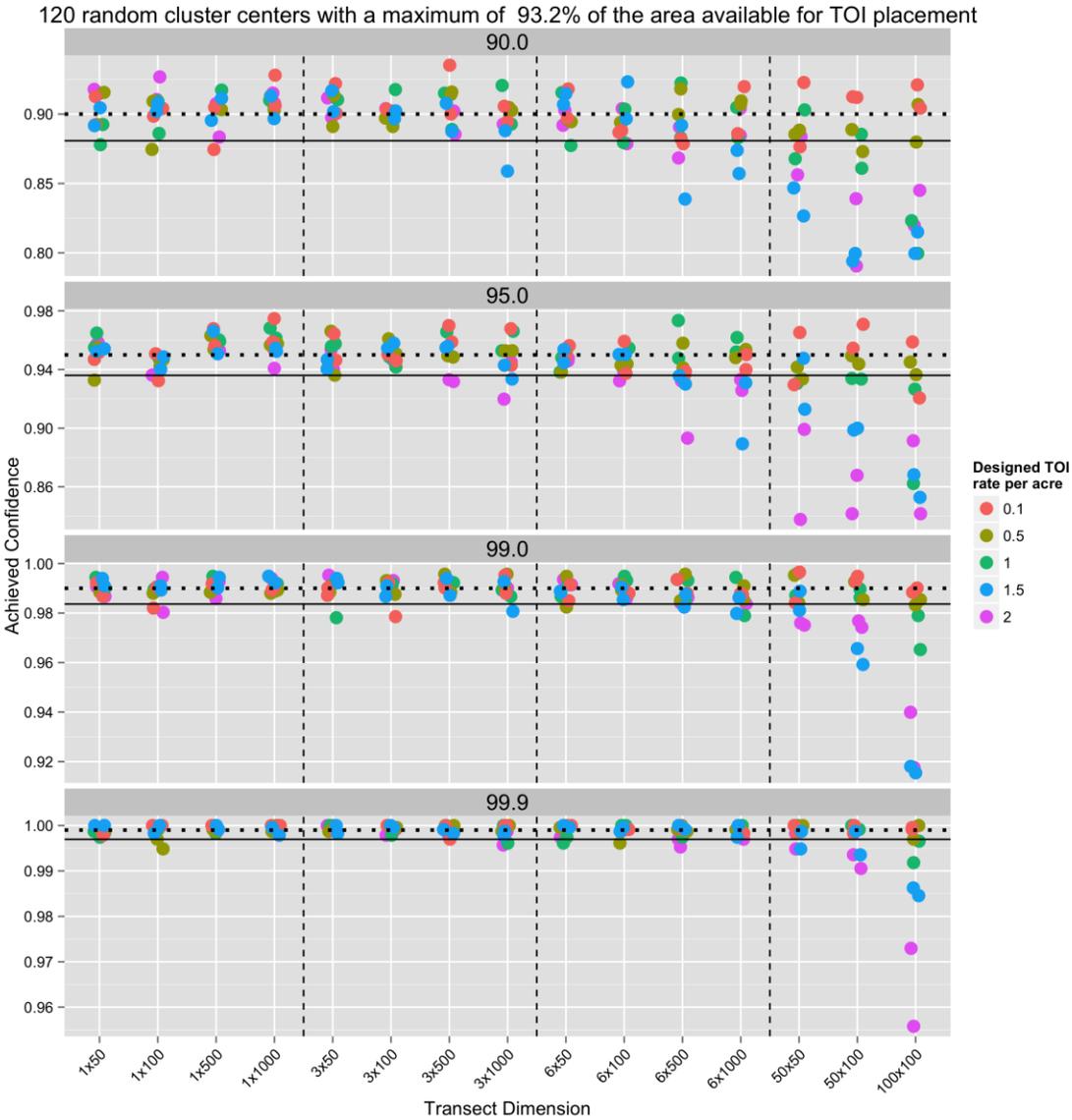
Figure C-9. Achieved confidence performance (y-axis) plots for 120 random cluster centers with all points within a square area of 15.4 acres around each grid center, which results in a maximum of 93.2% of the Motlow boundary area of 1989 acres having potential for TOI placement. The sampling unit dimensions are shown on the x-axis. The horizontal dotted line marks the designed confidenceand the solid horizontal line is the 3 standard deviation lower bound for confidence performance of a simulation study using 2300 simulations to evaluate confidence. The vertical lines separate the three transect widths and the grid based sampling units.

120 random cluster centers with a maximum of 100% of the area available for TOI placement
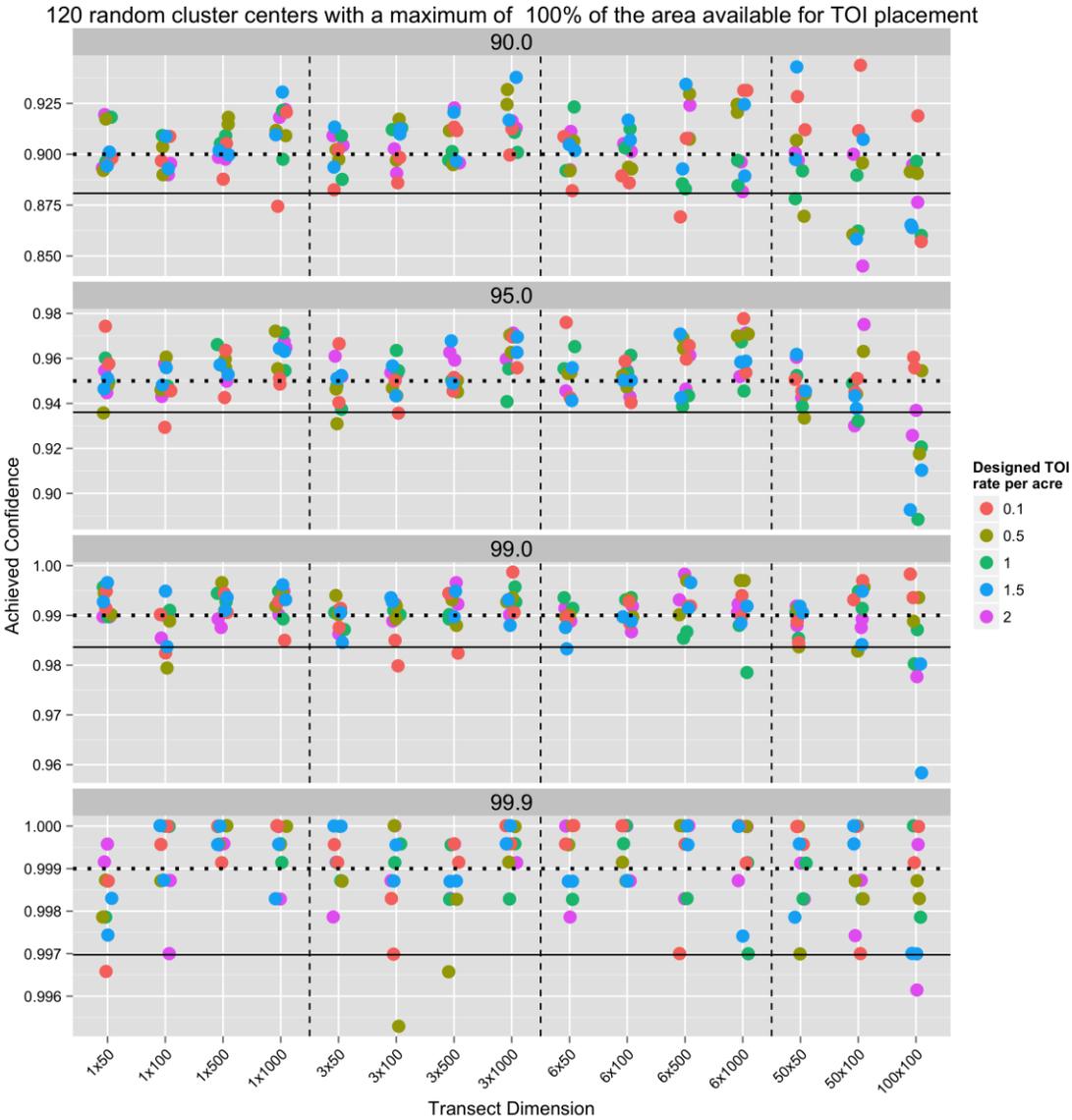
Figure C-10. Achieved confidence performance (y-axis) plots for 120 random cluster centers with all points within a square area of 61.8 acres around each grid center, which results in a maximum of 100% of the Motlow boundary area of 1989 acres having potential for TOI placement. The sampling unit dimensions are shown on the x-axis. The horizontal dotted line marks the designed confidence and the solid horizontal line is the 3 standard deviation lower bound for confidence performance of a simulation study using 2300 simulations to evaluate confidence. The vertical lines separate the three transect widths and the grid based sampling units.

120 random cluster centers with a maximum of 5.4% of the area available for TOI placement
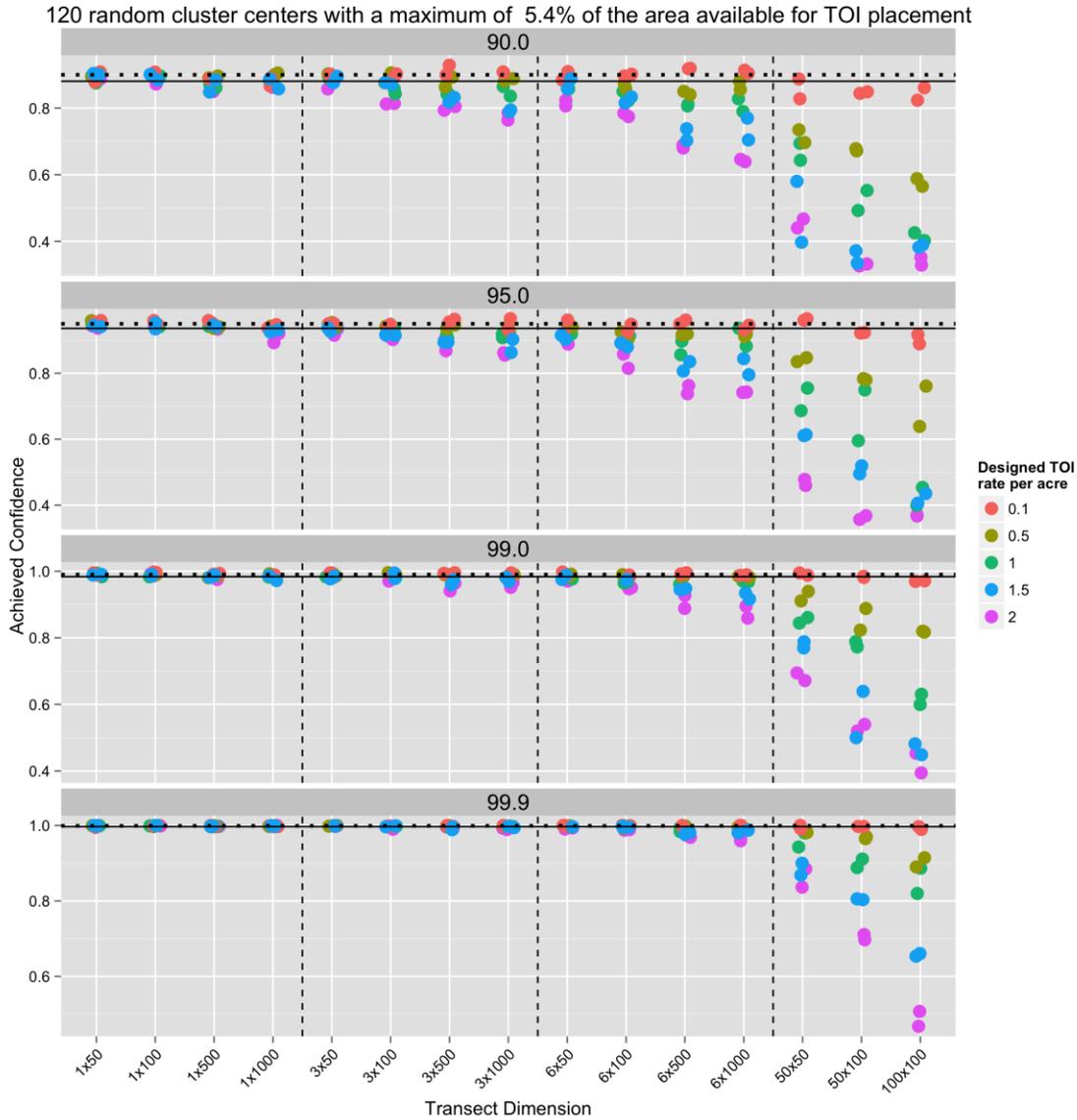
Figure C-11. Achieved confidence performance (y-axis) plots for 120 random cluster centers with all points within a square area of 0.9 acres around each grid center, which results in a maximum of 5.4% of the Motlow boundary area of 1989 acres having potential for TOI placement. The sampling unit dimensions are shown on the x-axis. The horizontal dotted line marks the designed confidenceand the solid horizontal line is the 3 standard deviation lower bound for confidence performance of a simulation study using 2300 simulations to evaluate confidence. The vertical lines separate the three transect widths and the grid based sampling units.

30 random cluster centers with a maximum of 5.8% of the area available for TOI placement
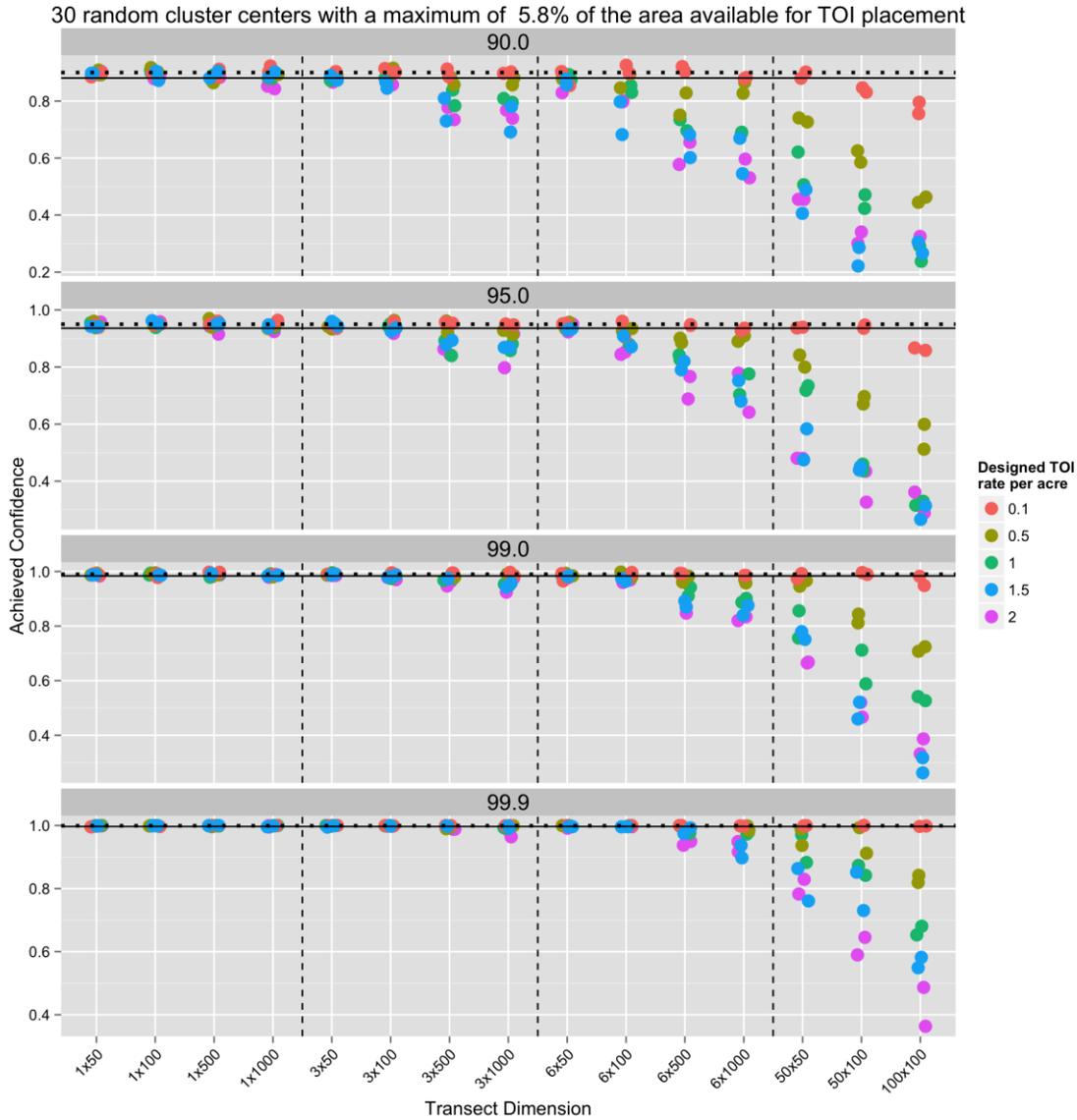
Figure C-12. Achieved confidence performance (y-axis) plots for 30 random cluster centers with all points within a square area of 3.9 acres around each grid center, which results in a maximum of 5.8% of the Motlow boundary area of 1989 acres having potential for TOI placement. The sampling unit dimensions are shown on the x-axis. The horizontal dotted line marks the designed confidenceand the solid horizontal line is the 3 standard deviation lower bound for confidence performance of a simulation study using 2300 simulations to evaluate confidence. The vertical lines separate the three transect widths and the grid based sampling units.
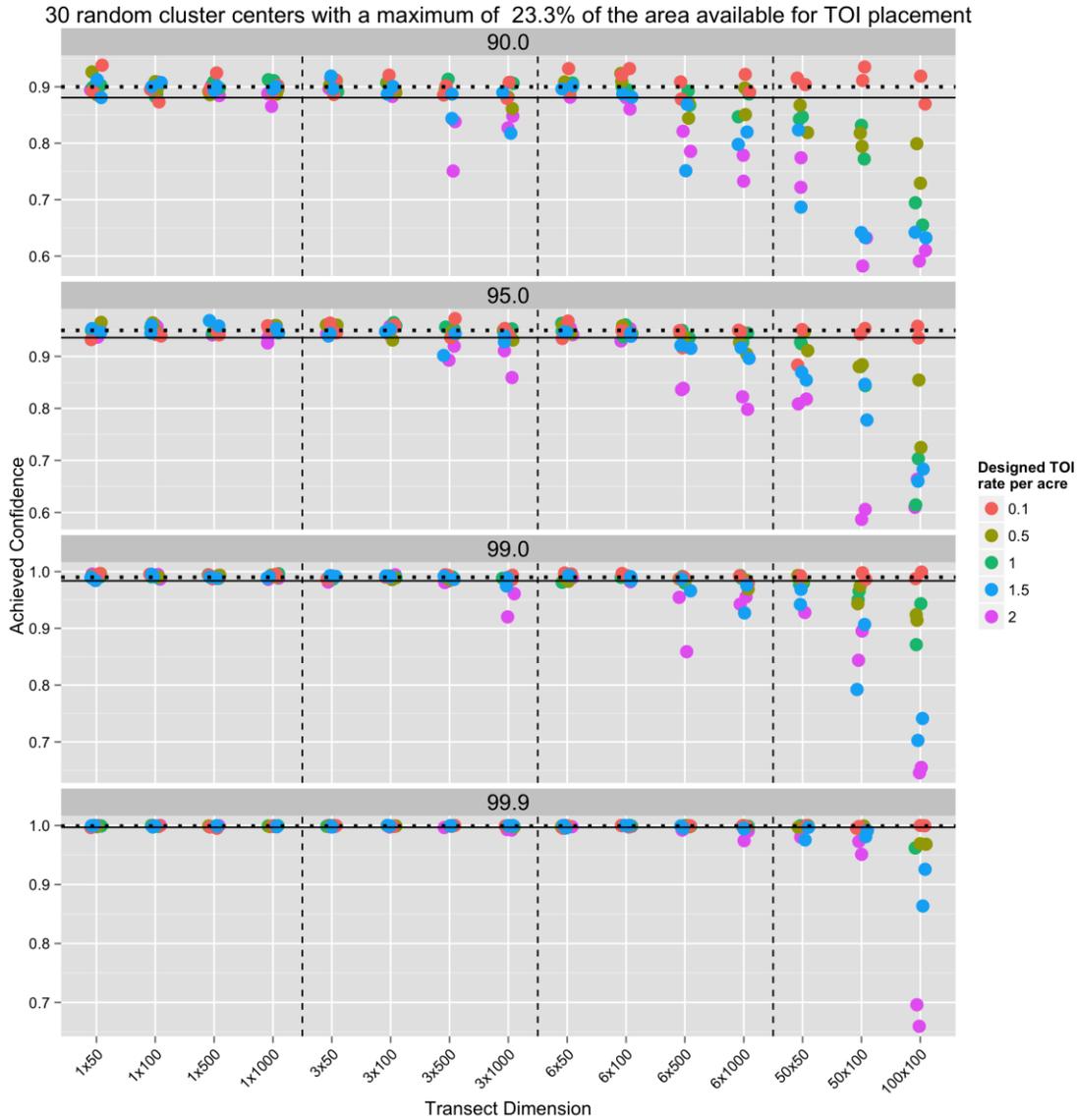
Figure C-13. Achieved confidence performance (y-axis) plots for 30 random cluster centers with all points within a square area of 15.4 acres around each grid center, which results in a maximum of 23.3% of the Motlow boundary area of 1989 acres having potential for TOI placement. The sampling unit dimensions are shown on the x-axis. The horizontal dotted line marks the designed confidenceand the solid horizontal line is the 3 standard deviation lower bound for confidence performance of a simulation study using 2300 simulations to evaluate confidence. The vertical lines separate the three transect widths and the grid based sampling units.
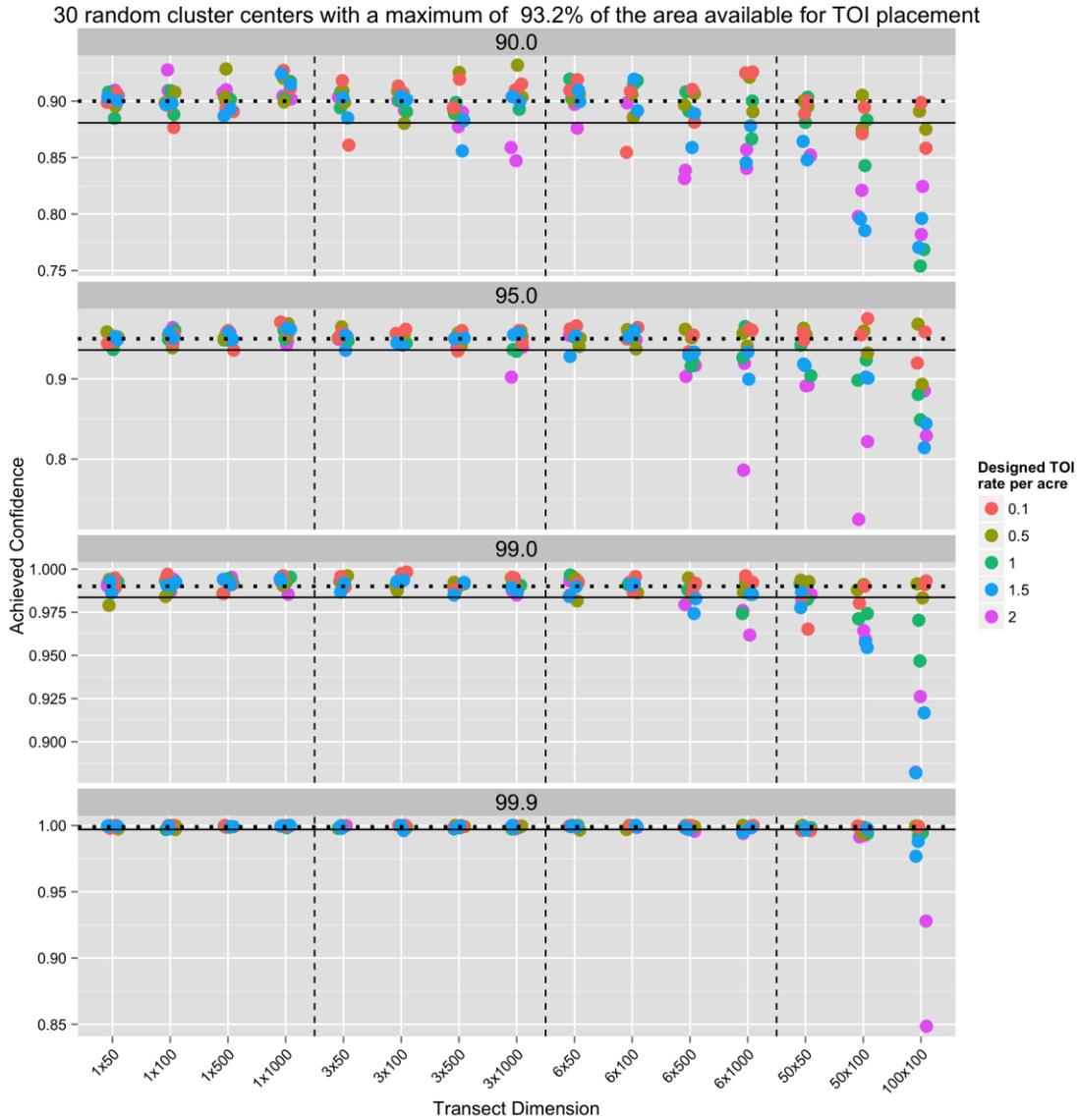
Figure C-14. Achieved confidence performance (y-axis) plots for 30 random cluster centers with all points within a square area of 61.8 acres around each grid center, which results in a maximum of 93.2% of the Motlow boundary area of 1989 acres having potential for TOI placement. The sampling unit dimensions are shown on the x-axis. The horizontal dotted line marks the designed confidence and the solid horizontal line is the 3 standard deviation lower bound for confidence performance of a simulation study using 2300 simulations to evaluate confidence. The vertical lines separate the three transect widths and the grid based sampling units.
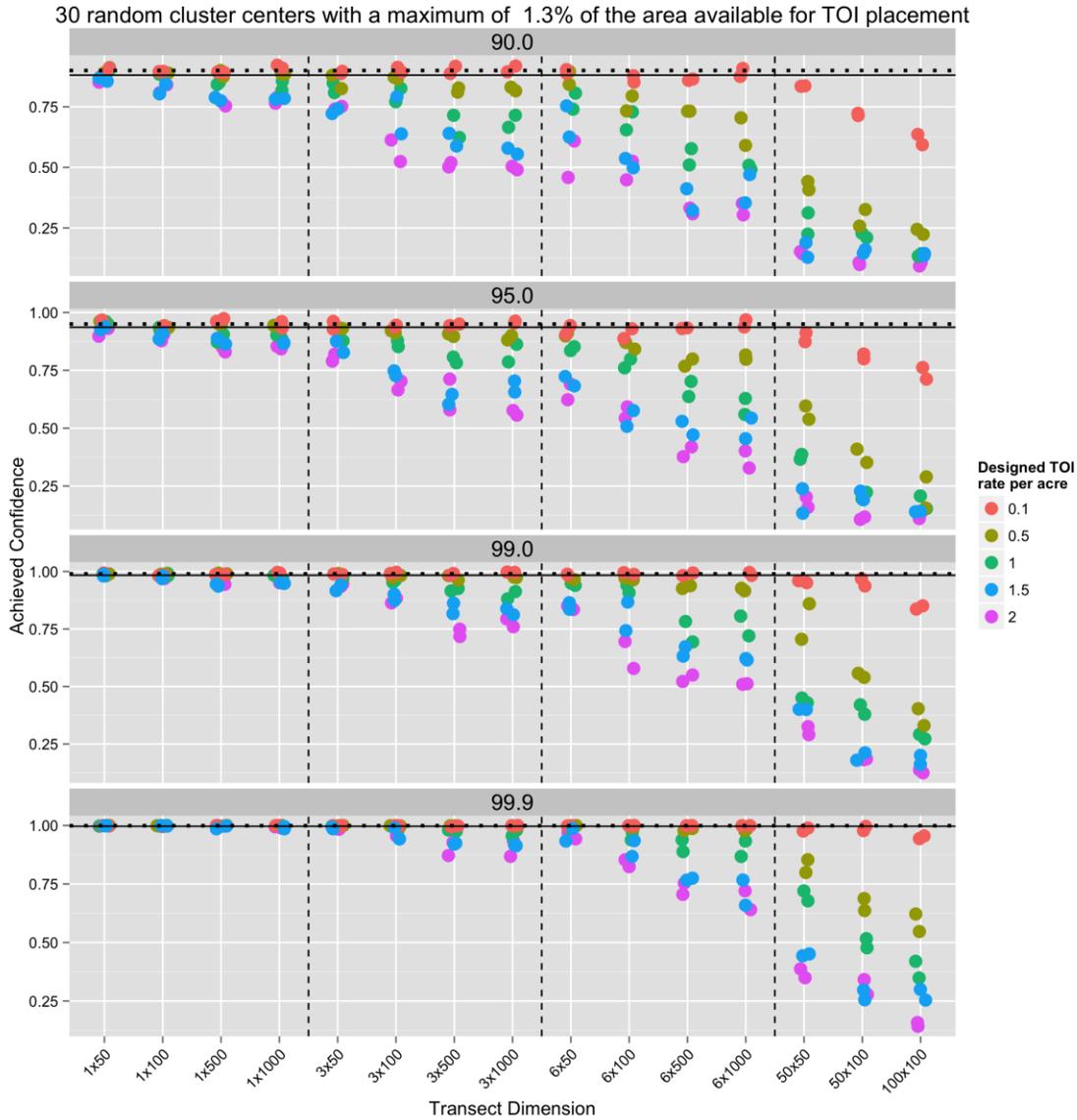
Figure C-15. Achieved confidence performance (y-axis) plots for 30 random cluster centers with all points within a square area of 0.9 acres around each grid center, which results in a maximum of 1.3% of the Motlow boundary area of 1989 acres having potential for TOI placement. The sampling unit dimensions are shown on the x-axis. The horizontal dotted line marks the designed confidenceand the solid horizontal line is the 3 standard deviation lower bound for confidence performance of a simulation study using 2300 simulations to evaluate confidence. The vertical lines separate the three transect widths and the grid based sampling units.

60 random cluster centers with a maximum of 11.6% of the area available for TOI placement
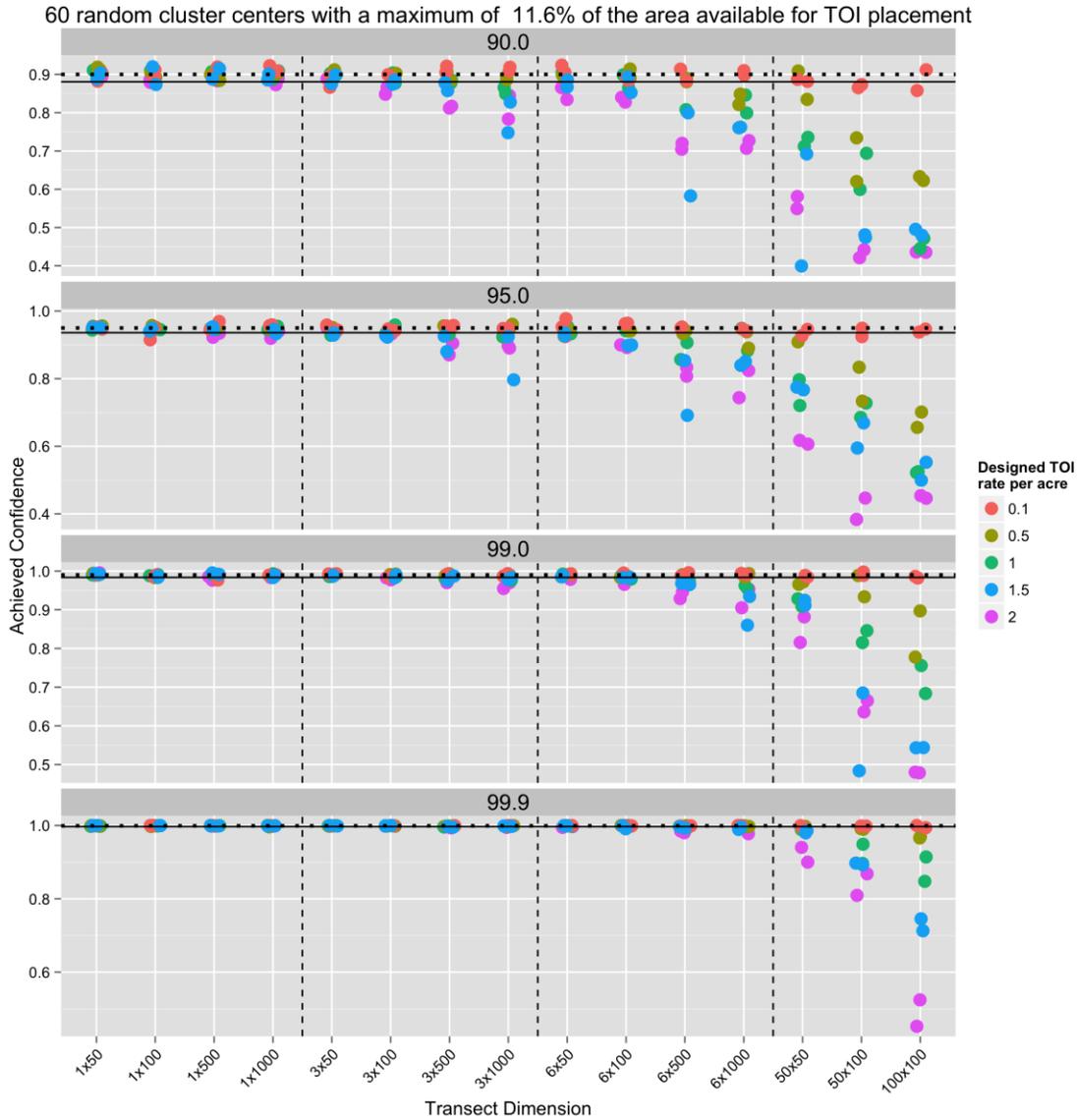
Figure C-16. Achieved confidence performance (y-axis) plots for 60 random cluster centers with all points within a square area of 3.9 acres around each grid center, which results in a maximum of 11.6% of the Motlow boundary area of 1989 acres having potential for TOI placement. The sampling unit dimensions are shown on the x-axis. The horizontal dotted line marks the designed confidenceand the solid horizontal line is the 3 standard deviation lower bound for confidence performance of a simulation study using 2300 simulations to evaluate confidence. The vertical lines separate the three transect widths and the grid based sampling units.

60 random cluster centers with a maximum of 46.6% of the area available for TOI placement
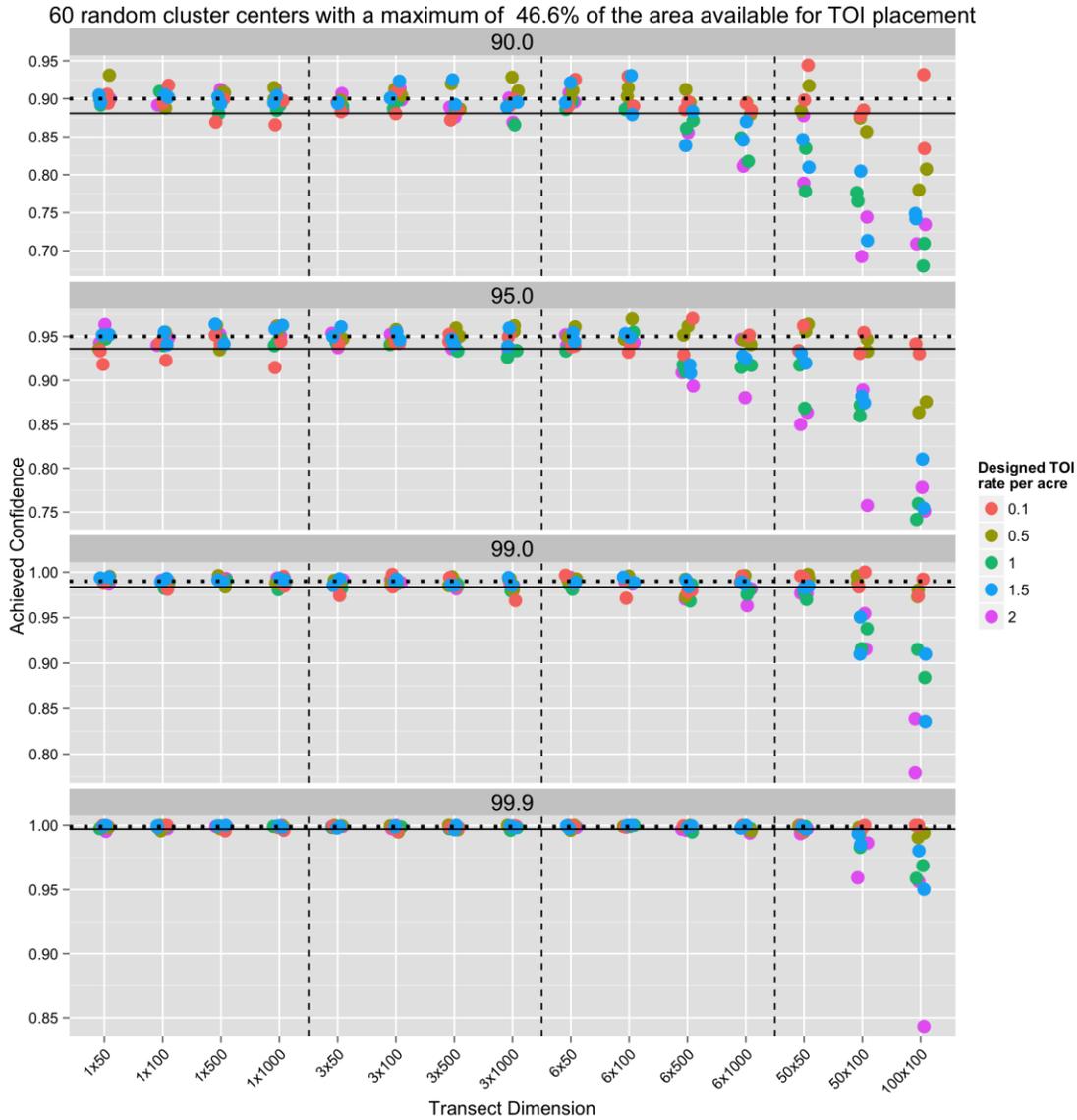
Figure C-17. Achieved confidence performance (y-axis) plots for 60 random cluster centers with all points within a square area of 15.4 acres around each grid center, which results in a maximum of 46.6% of the Motlow boundary area of 1989 acres having potential for TOI placement. The sampling unit dimensions are shown on the x-axis. The horizontal dotted line marks the designed confidenceand the solid horizontal line is the 3 standard deviation lower bound for confidence performance of a simulation study using 2300 simulations to evaluate confidence. The vertical lines separate the three transect widths and the grid based sampling units.
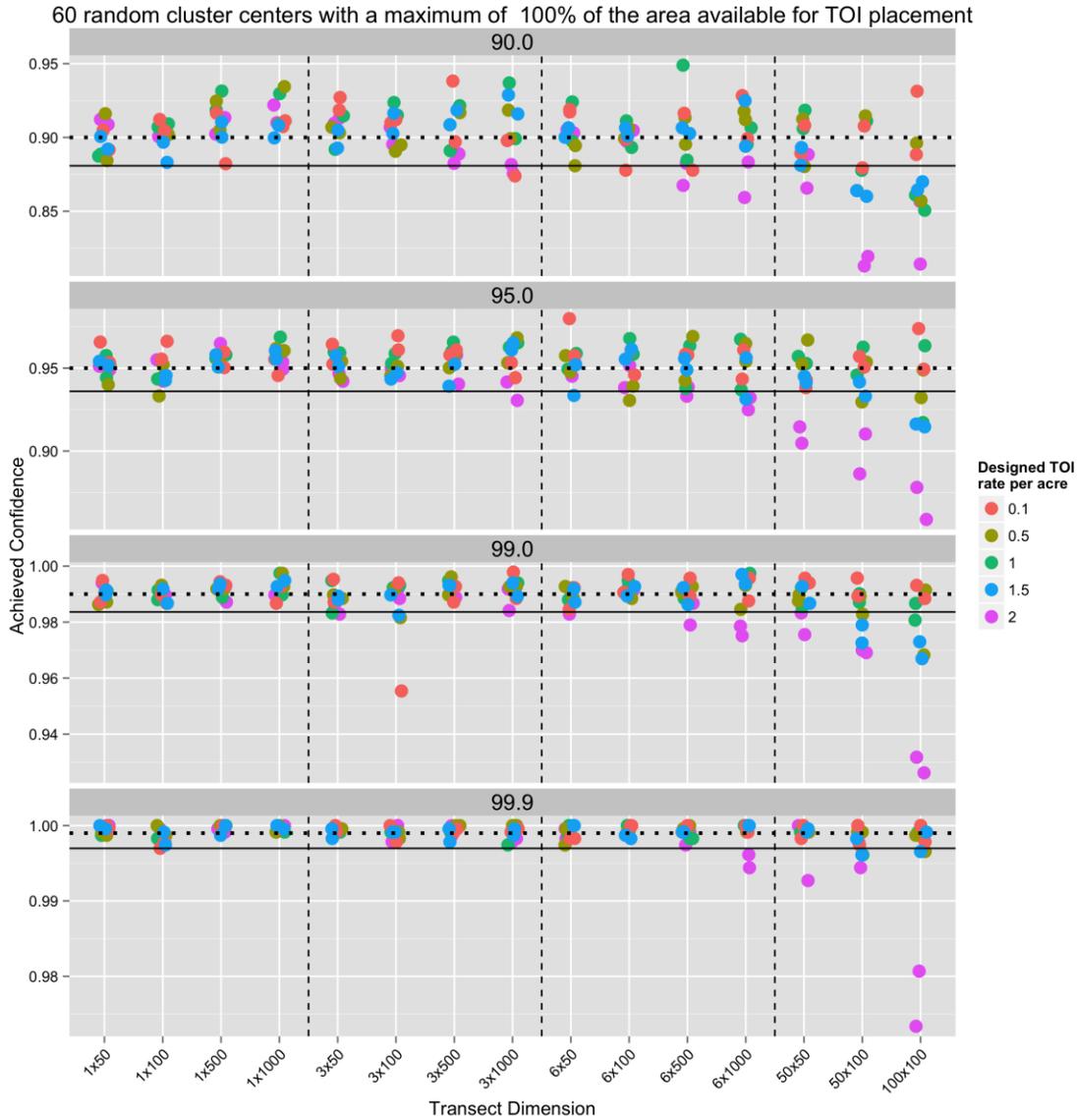
Figure C-18. Achieved confidence performance (y-axis) plots for 60 random cluster centers with all points within a square area of 61.8 acres around each grid center, which results in a maximum of 100% of the Motlow boundary area of 1989 acres having potential for TOI placement. The sampling unit dimensions are shown on the x-axis. The horizontal dotted line marks the designed confidenceand the solid horizontal line is the 3 standard deviation lower bound for confidence performance of a simulation study using 2300 simulations to evaluate confidence. The vertical lines separate the three transect widths and the grid based sampling units.

60 random cluster centers with a maximum of 2.7% of the area available for TOI placement
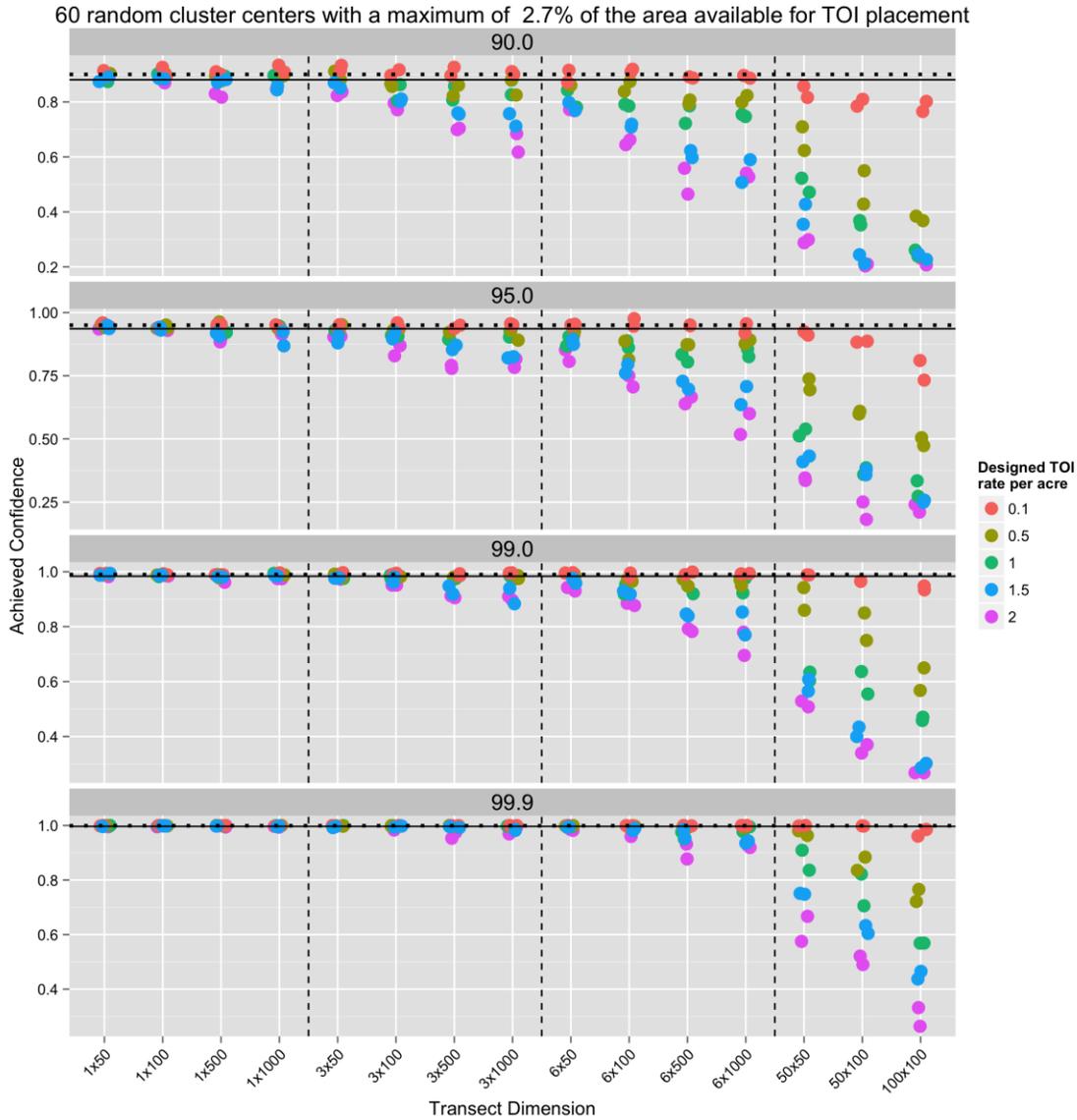
Figure C-19. Achieved confidence performance (y-axis) plots for 60 random cluster centers with all points within a square area of 0.9 acres around each grid center, which results in a maximum of 2.7% of the Motlow boundary area of 1989 acres having potential for TOI placement. The sampling unit dimensions are shown on the x-axis. The horizontal dotted line marks the designed confidenceand the solid horizontal line is the 3 standard deviation lower bound for confidence performance of a simulation study using 2300 simulations to evaluate confidence. The vertical lines separate the three transect widths and the grid based sampling units.